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# Monitoring for Malathion Residues in Lettuce, Onions and Fruit, After Aerial Spraying in Southern Manitoba, 1983.

S. Floyd Phillips and Dale B. McEachern

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## ABSTRACT

Urban centres in Southern Manitoba, Canada were sprayed with malathion to combat a potential epidemic of Western Equine Encephalitis. A specially equipped aircraft was used to apply ultra low volume insecticide at a rate of 210 mL/ha.

A study was undertaken to determine the degree to which vegetables and fruit grown in backyard gardens might be contaminated by the malathion. Samples of lettuce, green onion tops, strawberries, raspberries and apples were collected before and immediately after the aerial spraying. The samples were quick-frozen and stored at -45°C. A gas chromatograph with a flame-photometric detector (phosphorus mode) was used to analyze the samples after appropriate preparation.

More than 50 percent of the unwashed post-spray samples of lettuce and green onion tops exceeded the tolerable levels of 6.0 µg/g and 3.0 µg/g respectively. Malathion concentrations in fruit were less than 1.0 µg/g, well below the tolerable limit of 8.0 µg/g. Washing the lettuce samples reduced malathion residues to well below 6.0 µg/g. Field weathering reduced the malathion concentration in lettuce by 50 percent in the first 48 hours after application and the residue was almost totally dissipated after 14 days. No foliage damage attributable to malathion was observed.

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## I INTRODUCTION

On July 19, 1983, the Minister of Health, Province of Manitoba, declared a health emergency in Southern Manitoba because of a potential epidemic of Western Equine Encephalitis (WEE). As a result, an emergency aerial spraying program using the insecticide malathion was initiated to control adult mosquito populations of Culex tarsalis, the principal transmitter of the WEE virus. At the same time the Minister of the Environment announced that the Province of Manitoba would initiate a multi-facetted monitoring program to evaluate the aerial application of malathion. This report provides results of the vegetable and fruit monitoring program carried out by the Terrestrial Standards and Studies Section. The program was established to determine whether the malathion was contaminating human food, in particular, vegetables and fruit grown in backyard gardens.

Leaf lettuce was chosen as the primary sampling substrate because: (i) it was grown in most gardens and therefore was readily available, (ii) it had a relatively large surface area, a pre-requisite of a good receptor, (iii) the edible parts of the plant are exposed to the spray (iv), lettuce is eaten with no preparation except washing and (v) the analysis for contaminants is simplified because lettuce does not contain compounds which could interfere in the chemical analysis procedure. Samples of other substrates (onion, strawberry, raspberry and apple) were collected from a few locations for comparison.

A considerable amount of information appears in the literature concerning residues of several insecticides used in conventional crop spraying. Some studies have focused on malathion residues in crops and in soils but specific testing of residues in vegetables and fruits following ultra low volume applications by aircraft have not been reported. Conventional spraying of malathion, results in increased pesticide residues in lettuce, green onions, raspberries and apples (Kansouh et al. 1978, Smith et al. 1954, Wallis et al. 1957, Westlake and Butler 1953). Relevant studies of residues on leafy vegetables include that of Waites and Van Middelem (1957) on cabbage. Conventional spraying resulted in application rates which were 3 to 8 times higher than ultra low volume aerial spraying; nevertheless, the data are useful for comparative purposes.

## II METHODS

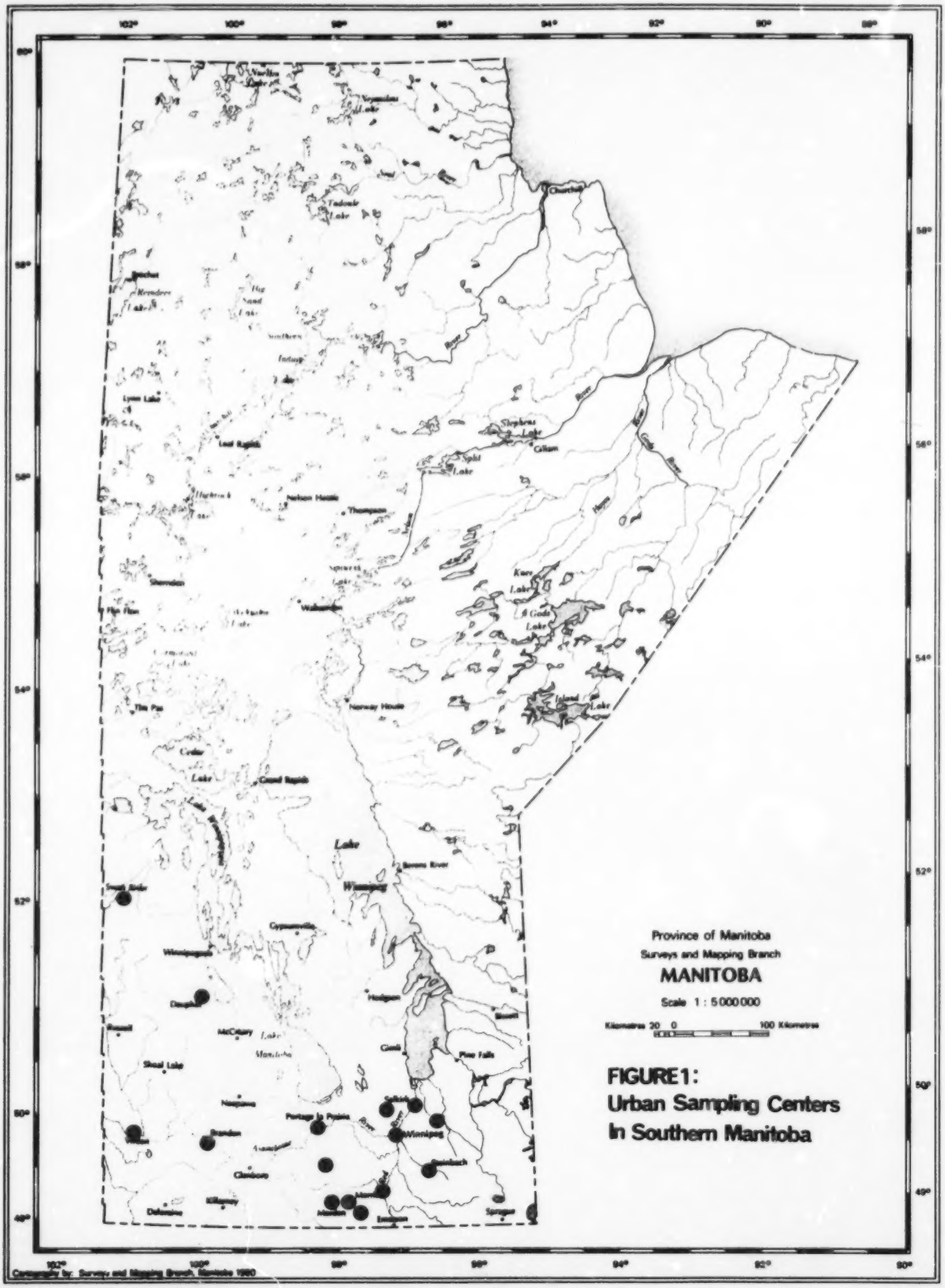
### A. Aerial Spraying

Cythion Ultra Low Volume (ULV) concentrate which is composed of 95% malathion, was chosen as the spraying agent. A specially equipped Conair DC6B aircraft was contracted to carry out the aerial spraying. Malathion application rate was 210 mL per hectare (3 fl. oz./acre); the aircraft flew at an altitude of 100 metres and a speed of

150 knots per hour. Flight lines were perpendicular to prevailing wind directions and were spaced at 0.8 km (0.5 miles) intervals. All spray applications were carried out in early morning or late evening when adult mosquitoes were theoretically most active. Spraying was restricted to those mornings and evenings when the wind speed was less than 16 km/h.

B. Vegetable and Fruit Sampling

The monitoring program was limited to lettuce, green onion tops, strawberries, raspberries and apples. The sampling was conducted in 15 cities/towns in Southern Manitoba (Figure 1) where the spraying occurred (See Appendix 1 for maps showing site locations). Samples were collected for each of the two spray events in Winnipeg. As much as possible, work associates or acquaintances of Terrestrial Standards and Studies staff were contacted in various areas of each city/town and asked if they would assist by allowing us to sample in their garden. If the first contact did not have lettuce in their yard, they would usually refer us to someone on their street who did. In communities where there was no known contact, the staff in Manitoba Agriculture regional offices assisted by contacting their work associates or acquaintances. In at least four towns, there was insufficient lead time to set this contact process in motion. In those cases, we selected neighbourhoods and canvassed homes until we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Cartography by Surveys and Mapping Branch, Manitoba 1990

**FIGURE 1:**
**Urban Sampling Centers In Southern Manitoba**

found a resident with lettuce in their garden. We received excellent cooperation from the public and without exception, all who had lettuce were willing to participate.

Onions, raspberries and apples were sampled from a few locations, the selection process being dependent for the most part on availability. Strawberries were sampled from four U-Pick strawberry farms which were within the designated spray blocks.

Pre-spray samples were collected before the spraying occurred to determine the background levels in each garden. Sampling was carried out between 20 minutes and 2 hours of the time that the spray plane passed each sample location. If we were on-site when a given location was sprayed, we would delay sampling for 20 minutes to allow the malathion to settle. The logistics of ground travel made it impossible to keep up to the aircrafts progress so locations sprayed later in a spray event could not be sampled immediately. Although it was usually possible to sample within one hour, delays of up to two hours occurred at a few sites.

Four gardens in Winnipeg were monitored over a longer post-spray duration; a second sample was collected 2 to 5 days after spraying and the third and fourth samples at 7 and 14 days respectively. The purpose of this "extended" monitoring was to study the rate of malathion degradation under field conditions.

Sample collection involved snapping leaves off the lettuce plants with our fingers, at random along a row, until the required sample (30 grams minimum) was obtained. Two samples (unwashed and washed) were collected from each garden provided that enough lettuce was available. Only washed samples were collected from gardens which had a limited supply of lettuce. Washing involved alternately rinsing with tap water and squeezing the water out, a process which was repeated 5 times. All samples were placed in 500 mL glass jars with screw caps. The jars had been pre-cleaned with acetone and hexane and the caps were lined with acetone/hexane-washed aluminum foil.

Onions were sampled in a similar way to the lettuce, by snapping leaves off at random along a row until the necessary sample was obtained. Only unwashed onion samples were collected. Strawberries and raspberries were sampled by picking ripe fruit at random along both sides of a row until the necessary sample was accumulated. Similarly, apples were sampled by selecting fruit at random from various parts of a tree. The apples were still green in July when the sampling occurred. All strawberry, raspberry and apple samples were collected in the unwashed condition.

The samples were frozen within 5 minutes of collection, by placing them in a cooler lined with dry ice (-78°C). The purpose of the low temperature quick-freezing was to prevent the breakdown of malathion.

Studies of malathion degradation at different storage temperatures suggest that breakdown can be rapid at temperatures above 0°C (Koivistoinen et al. 1964 a). Studies of degradation at -18°C were inconclusive but the potential for malathion degradation at that storage temperature was not ruled out (Koivistoinen et al. 1964 b). Our study proposed much lower storage temperatures as an additional measure of protection. The samples were transported to a -40°C freezer at the Ellice Building, University of Manitoba for initial storage but were subsequently transferred to a -45°C freezer at the Fresh Water Institute.

The analyses were carried out by the W. M. Ward Technical Services Laboratory. A 30-gram subsample of the frozen sample was homogenized with acetonitrile, and after appropriate dilution with water, was partitioned with petroleum ether. The petroleum ether extract was then dried through $Na_2SO_4$ and concentrated. The extract was then analyzed using a gas chromatograph equipped with a flame photometric detector in the phosphorous mode (U.S. Food and Drug Administration 1982). Results were confirmed on two detectors and a GC mass spectrophotometer was used to confirm the malathion compound in one of the samples. A subsample of uncontaminated lettuce from La Riviere was analyzed with each batch of 10 samples as a quality assurance check. A further quality assurance check was implemented with each batch, by analyzing a subsample of the uncontaminated lettuce which had been spiked with a known quantity of malathion. The mean analytical recovery rates were 91 percent and 96 percent at concentrations of 0.015 ng/µL and 0.15 ng/µL respectively.

## III RESULTS AND DISCUSSION

### A. Spray Application Rate

The ultra low volume application rate of malathion was 210 mL/ha. However, there was considerable variability in the amount which reached the ground. The Environmental Protection Service, Environment Canada, carried out a droplet monitoring program and observed deposition ranging from 1 mL/ha to 354 mL/ha (Youmans 1983).

### B. Vegetable and Fruit Monitoring

A total of 249 lettuce samples, 28 green onion samples, 8 strawberry samples, 11 raspberry samples and 10 apple samples were analyzed in the course of this monitoring program. Results for each sample substrate will be dealt with separately in the discussion which follows.

#### 1. Lettuce

Concentrations of malathion found in pre-spray compared with post-spray lettuce samples from the City of Winnipeg are presented in Table 1. Data from other cities and towns in Southern Manitoba are shown in Table 2. Before the first spray event, low levels of malathion (<0.002 µg/g to 0.065 µg/g) were present in unwashed lettuce from backyard gardens in Winnipeg. The average concentration

(Table 3) before the first spray event was 0.018 µg/g in Winnipeg compared with 0.035 µg/g for lettuce from other cities/towns in Southern Manitoba. Washing the lettuce reduced average pre-spray concentrations of malathion to 0.005 µg/g and 0.002 µg/g for Winnipeg and Southern Manitoba respectively.

Comparison of the average malathion concentrations in Winnipeg before the first and the second spray event suggest that malathion levels had increased. However there is no proof that malathion residues from the first spray event caused the increase; natural variablity in the data was high and could account for the small differences noted.

Applications of malathion by aerial spraying resulted in elevated concentrations of malathion in approximately 50 percent of the lettuce samples. The data were highly variable, ranging from pre-spray background levels of <0.002 µg/g to a high of 24.6 µg/g. This is consistent with the variability in measured deposition rates which ranged from 1 mL/ha to 354 mL/ha (Youmans 1983). Some variability in deposition was expected because the flight lines were spaced at 0.8 km (0.5 mi) intervals and variable atmospheric influences such as wind and thermal gradients, as well as the effects of surface topography and landscape structures, could have affected the spray drift.

The post-spray unwashed lettuce sample from site 9, in the Point Douglas area of Winnipeg, had a malathion concentration of 78.4 µg/g which appears to be an anomaly in that it was three times higher than

the next largest concentration. However, re-analysis of the sample on the gas chromatograph confirmed the concentration, and follow up analysis by GC mass spectrophotometry positively identified the presence of high levels of malathion. The reason for the high deposition at site 9 is not known. A malfunctioning nozzle could have been suspected if the site had been directly below a flight line but in fact it was located between flight lines. The other possibility is that the combination of wind direction, wind speed, and the influence of tall trees, two storey houses and the proximity of the Red River with its associated flood control dyke, could have combined to funnel air currents to the site. In any case, the 78.4 µg/g value was an obvious outlier and was not used in the calculation of mean values.

Even though site 11 - Winnipeg and site 1 - Selkirk were beyond the boundaries of prescribed spray blocks (approximately 2 km north), slightly elevated levels of malathion were found in post-spray samples of lettuce. It appears from these data that spray drift may carry the malathion up to 2 km beyond the designated spray boundaries.
Site 1 - Selkirk was downwind of the Selkirk spray block so the drift was not unexpected, however, site 11 - Winnipeg was slightly upwind of the Winnipeg spray block but was still affected.

The average post-spray concentration in unwashed lettuce from Winnipeg was 6.66 µg/g (range 0.164 to 15.6 µg/g) for the first spray event, 7.39 µg/g (range 0.093 to 24.6 µg/g) for the second spray event and 7.38 µg/g (range <0.002 to 24.6 µg/g) for other

cities/towns in Southern Manitoba (Table 3). After the first Winnipeg spray event, 50 percent of the unwashed lettuce samples exceeded the tolerable level of 6.0 µg/g for malathion in lettuce (Health and Welfare Canada, Food and Drug Directorate 1975). Similarly, 43 percent of the samples from the second Winnipeg spray event and 52 percent of post-spray samples from other cities/towns had concentrations of malathion exceeding 6.0 µg/g.

The malathion residues found in lettuce compare well with other published reports. Smith et al. (1954) found malathion residues of up to 22 µg/g following fumigation with a 15 percent aerosol at a rate of 1.5 g/1000 cu ft. Assuming that the height of the greenhouse was 10 feet, the rate of application would have been 1.5 g/100 sq. ft. or 1313 mL/ha. Wallis et al. (1957) applied malathion at a rate of 1.75 lb./acre (1595 mL/ha) to lettuce; the resulting one hour post-spray residue of malathion was 26.1 µg/g. Kansouh et al. (1978) reported much higher residues of 91 µg/g following the application of 57 percent malathion (emulsifiable concentrate) at a rate of 1.0 L/feddan (equivalent to 1356 mL/ha active ingredient). The ultra low volume application rate in Manitoba's aerial spraying program was much lower (210 mL/ha) but some samples had residues as high as those reported by Smith et al. (1954) and Wallis et al. (1957). This probably resulted from the higher than prescribed spray deposition in some areas, a fact which is supported by the droplet monitoring results (Youmans 1983).

Although malathion residues in some unwashed lettuce were too high for safe human consumption, a simple water washing proved to be effective in reducing concentrations to acceptable levels. The average concentration in washed lettuce from Winnipeg was 0.85 µg/g and 1.72 µg/g for the first and second spray events respectively; that from Southern Manitoba was 0.83 µg/g. This agrees with evidence presented by Wallis et al. (1957) wherein the malathion residues in parsley were reduced from 36 to 3 µg/g by washing for 1 minute. Some of the residue is rinsed off the plant material but the process of hydrolysis may also degrade some of the malathion, especially at strongly basic pH's (Cowart et al. 1971 and Konrad et al. 1969).

The data presented in Table 4 demonstrate the natural degradation rate of malathion in lettuce after the spray event. Sites 8 and 10 (Winnipeg) provide the best examples because the data are complete. At site 10, the malathion concentration in unwashed lettuce was reduced from 8.8 µg/g to 1.74 µg/g over a two day period. At site 8, the percentage decrease was less, but within two days, natural degradation was effective in reducing the level below the tolerable limit of 6.0 µg/g. Degradation of malathion continued through the 14 day test period, resulting in final concentrations which were within the pre-spray background range. These data also show that even when very little malathion was present, washing the lettuce was still effective in reducing the concentration.

Other studies support the evidence that residues of malathion dissipate fairly rapidly with time after application. For the outside leaves of cabbage, Waites and Van Middelem (1957) found that 40 percent dissipated within 48 hours and 80 percent after 7 days. Similar results were obtained in the studies of Smith et al. (1954). Wallis et al. (1957) determined natural degradation of malation in lettuce to be 50 percent over a seven day period. In most instances, concentrations are reduced to near zero after 14 days (Smith et al. 1954). More recently, Kansouh et al. (1978) reported a 50 percent reduction of malathion residues in lettuce within 3 to 5 days and further decreases at the 7 and 9 day post-application intervals. However, the initial deposit was 4 to 5 times those of Wallis et al. (1957) and Smith et al. (1954). As a result, the 9 day residue was relatively high (22 to 24 µg/g). If the plants are growing vigorously, the increase in weight could account for some of the reduction in malathion levels. In the present study, the lettuce which was tested over the two week period was mature and not growing rapidly. We believe that malathion degradation rather than the inclusion of new growth was the predominant factor operating to reduce concentrations over time.

2. Onions

Unwashed green onion tops were sampled from 14 gardens to compare malathion concentrations with those found in lettuce (Table 5). The pre-spray samples had low malathion levels which were usually below

the detection limit of 0.002 µg/g. Fifty-eight percent of the post-spray samples exceeded the tolerable level of 3.0 µg/g for malathion in onions (Health and Welfare Canada, Food and Drug Directorate 1975). The mean concentration of malathion in unwashed pre-spray samples was 0.003 µg/g and that in samples collected within one hour of the aerial spray application was 4.9 µg/g (range 0.01 µg/g to 15.5µg/g). Although washed post-spray onion samples were not tested, we feel that washing would probably have reduced the malathion concentrations to below the 3.0 µg/g tolerance limit. Washing the sample not only rinses some of the malathion off the plant material but may also promote some hydrolysis of malathion residues (Smith et al. 1954, Konrad et al. 1969 and Cowart et al. 1971).

With the exception of three sites, there was generally good agreement between the malathion in onions and that in lettuce from the same garden. The concentrations were usually slightly lower in the onion tops which might be explained by the greater mass per unit area of the receptor surface. Onions from site 10 in Winnipeg and site 4 in Carman had less than 10 percent of the malathion concentrations that were found in the lettuce samples. On the other hand, onions from site 4 in Brandon, had malathion levels more than twice that of lettuce from the same garden. We do not know the cause of those anomalies.

Smith et al.(1954) reported a malathion concentration of 10.56 µg/g in green onion tops which had been sprayed with malathion

(emulsifiable concentrate) at 911 mL/ha (1 lb/acre). Their application rate was four times the rate of 210 mL/ha which was applied in the Manitoba aerial spraying program reported herein. It is obvious from the site-to-site variability in our data that the spray distribution at ground level was not uniform. Given the fact that some sites may have received very little malathion while others may have received more than the prescribed application, the present data seem to coincide fairly well with those reported by Smith et al. (1954).

3. Strawberries, Raspberries and Apples

Pre-spray malathion concentrations in strawberries were below the detection limit of 0.002 µg/g (Table 6). Malathion concentrations in post-spray samples were slightly elevated with an average of 0.251 µg/g and a range of 0.036 to 0.706 µg/g. Similar results were obtained from the raspberry samples; the mean post-spray concentration was 0.254 µg/g with a range of 0.053 to 0.444 µg/g. Apples on the other hand had relatively low post-spray malathion residues with a mean of 0.052 µg/g and a range of 0.002 to 0.109 µg/g. No data on residues in these fruit crops following ultra low volume aerial application have been reported in the literature. Studies using conventional spray applications of malathion as emulsifiable concentrate (E.C.) have reported higher residues but that could be attributed to the higher rates of application and the different spray angle.

Wallis et al. (1957) found residues in red raspberry ranging from 4.0 to 9.8 µg/g within one hour of the application of 1.75 lb/acre (1595 mL/ha) of malathion (E.C.). That was 8 times higher than the ultra low volume application of 210 mL/ha in the present study. Furthermore, in our study, the leaves of the raspberry probably protected the fruit from direct deposition of the spray. The spray from hand sprayers, as per Wallis et al. (1957), would have increased the probability of direct contact because the nozzle would have been directed horizontally, and at that angle the foliage would not provide as much protection to the fruit.

Westlake and Butler (1953) studied malathion residues in apple fruit after it was sprayed with an emulsifiable concentrate at different concentrations. At a rate of 0.31 lb per 100 gal, the residue was 1.0 µg/g and at 0.5 lb/100 gal, the residue ranged from 1.0 to 1.2 µg/g. The low residues which were found on apples in the present study are attributed to lower application rates plus the nearly vertical deposition. With aerial spray, the leaves provide more protection to the fruit compared with the more horizontal application by conventional sprayers.

There are no published data on residues of malathion in strawberries. In the present study, concentrations were similar to those found in raspberries. Because the fruit is usually under the leaves, it is protected to some degree from direct contact by the aerially applied malathion.

The concentration of malathion in strawberries and raspberries was much lower than that found in lettuce and onions. Two probable factors which combined to produce that result are: (i) the fruit was usually under the leaves and was thus protected (ii) the fruit had a greater mass per unit surface area than lettuce or onions and thus the concentration was lower. The fact that apples have a much higher ratio of mass to surface area than small fruits probably explains why apples had the lowest residues.

C. Malathion Phytotoxicity

While revisiting gardens after the spray application, the plant material was examined to see if the spray had caused any phytotoxic symptoms such as leaf-burn, leaf curling or abnormal leaf drop. There were no observed phytotoxic symptoms at the sample gardens. Furthermore, detailed examination of plants in other gardens, where the residents feared that malathion damage had occurred, revealed that powdery mildew as well as insects such as spider mites, aphids, and flea beetles had caused the foliage symptoms.

## IV CONCLUSIONS

1. Aerial application of malathion to control a potential outbreak of Western Equine Encephalitis caused concentrations of the insecticide in unwashed lettuce to exceed the tolerable level established by Health and Welfare Canada.

2. The deposition of malathion was highly variable, but up to 52 percent of lettuce had been contaminated above the tolerable concentration of 6.0 µg/g.

3. Actual malathion concentrations range to 3 or 4 times the guideline with unexpected frequency, and one lettuce sample had an inexplicably high concentration of 78.4 µg/g.

4. Washing the lettuce was effective in reducing the malathion concentrations well below the tolerable limit.

5. Natural degradation of malathion was rapid, resulting in a 50% reduction in the initial 48 hour period and almost total degradation within 14 days.

6. Green onion tops generally contained lower malathion residues than lettuce but since the tolerable limit for onions is lower e.g. 3.0 µg/g, 58 percent of the unwashed samples exceeded the Health and Welfare Canada guideline.

7. Malathion residues in unwashed strawberries, raspberries and apples were well below 1.0 µg/g which provides a good safety margin relative to the tolerable limit of 8.0 µg/g. Protection by foliage and a higher mass to surface area ratio are cited as factors contributing to the lower malathion concentrations in fruits.

8. There were no observed cases where the ultra low volume application of malathion caused visible damage to plant foliage.

TABLE 1: Malathion concentration (µg/g) in lettuce samples collected from backyard gardens in Winnipeg.

| Site No. | First Spray Event | | | | Second Spray Event | | | |
|---|---|---|---|---|---|---|---|---|
| | Pre-Spray | | Post-Spray | | Pre-Spray | | Post--Spray | |
| | unwashed | washed | unwashed | washed | unwashed | washed | unwashed | washed |
| 1 | 0.012 | <0.002 | - | 0.471 | 0.008 | 0.003 | 5.31 | 0.617 |
| 2 | <0.002 | <0.002 | - | 0.216 | - | <0.002 | - | 0.215 |
| 3 | <0.002 | <0.002 | - | 0.711 | - | - | - | - |
| 3* | - | - | - | - | - | 0.007 | - | 0.090 |
| 4 | 0.005 | <0.002 | - | 0.084 | 0.008 | 0.041 | 24.6 | 7.86 |
| 5 | 0.055 | 0.005 | 15.6 | 1.95 | 0.012 | <0.002 | 1.09 | 0.295 |
| 6 | 0.065 | 0.010 | 2.58 | 0.319 | 0.005 | 0.002 | 0.170 | 0.066 |
| 7 | 0.038 | 0.003 | 4.38 | 0.184 | - | - | - | - |
| 7* | - | - | - | - | - | 0.005 | - | 1.83 |
| 8 | - | - | 0.164 | 0.136 | 0.052 | 0.004 | 11.7 | 4.02 |
| 9 | 0.002 | 0.002 | 78.4** | 0.605 | - | - | - | - |
| 9* | - | - | - | - | 0.031 | 0.006 | 0.093 | 0.073 |
| 10 | <0.002 | <0.002 | 10.6 | 1.98 | 0.042 | 0.009 | 8.80 | 3.24 |
| 11*** | <0.002 | <0.002 | 0.132 | 0.122 | <0.002 | 0.087 | 0.042 | 0.052 |
| 12 | <0.002 | 0.020 | - | 2.70 | - | 0.012 | - | 0.584 |
| Mean | 0.018 | 0.005 | 6.66 | 0.85 | 0.022 | 0.008 | 7.39 | 1.72 |

* - Alternate for second spray event.
** - Outlier, not included in calculations
*** - Outside of designated spray block; data not used in calculation of means or percentages

TABLE 2. Malathion concentration (µg/g) in lettuce samples from backyard gardens in cities/towns in Southern Manitoba (excluding Winnipeg)

| City/Town | Site No. | Pre-Spray | | Post-Spray | |
|---|---|---|---|---|---|
| | | Unwashed | Washed | Unwashed | Washed |
| Altona | 1 | <0.002 | <0.002 | 0.033 | 0.012 |
| | 2 | <0.002 | <0.002 | 0.023 | 0.009 |
| | 3 | <0.002 | <0.002 | 0.008 | 0.011 |
| Beausejour | 1 | <0.002 | <0.002 | 15.3 | 1.00 |
| | 2 | <0.002 | <0.002 | 10.0 | 0.768 |
| | 3 | <0.002 | <0.002 | 20.6 | 0.519 |
| Brandon | 1 | <0.002 | 0.004 | 1.57 | 0.452 |
| | 2 | <0.002 | <0.002 | 7.28 | 1.76 |
| | 3 | <0.002 | 0.002 | 12.3 | 2.85 |
| | 4 | <0.002 | 0.003 | 6.44 | 1.81 |
| Carman | 2 | <0.002 | 0.003 | 10.9 | 0.460 |
| | 3 | <0.002 | <0.002 | 3.36 | 0.172 |
| | 4 | <0.002 | <0.002 | 14.6 | 0.575 |
| Dauphin | 1 | 0.002 | <0.002 | 3.02 | 0.752 |
| | 2 | 0.002 | <0.002 | 3.02 | 0.752 |
| | 3 | 0.003 | 0.003 | 8.42 | 1.27 |
| | 4 | 0.003 | 0.003 | 11.4 | 0.436 |
| Morden | 1 | <0.002 | <0.002 | 14.8 | 1.20 |
| | 3 | <0.002 | <0.002 | 2.62 | 0.159 |
| Morris | 1 | <0.002 | 0.002 | 4.36 | 1.18 |
| | 2 | <0.002 | <0.002 | 9.99 | 1.14 |
| Portage la Prairie | 1 | 0.004 | <0.002 | 1.69 | 0.273 |
| | 2 | 0.002 | <0.002 | 1.14 | 0.406 |
| | 3 | 0.007 | <0.002 | 0.551 | 0.171 |
| | 4 | <0.002 | <0.002 | 0.843 | 0.166 |
| Selkirk | 1* | 0.004 | <0.002 | 0.180 | 0.221 |
| | 3 | <0.002 | <0.002 | 24.6 | 0.973 |
| | 4 | <0.002 | <0.002 | 8.35 | 1.01 |
| Steinbach | 1 | <0.002 | 0.010 | 1.79 | 0.347 |
| | 2 | <0.002 | <0.002 | <0.002 | <0.002 |
| | 3 | <0.002 | <0.002 | <0.002 | <0.002 |
| Stonewall | 1 | <0.002 | <0.002 | 0.372 | 0.198 |
| | 2 | <0.002 | <0.002 | 2.30 | 0.418 |
| | 3 | <0.002 | <0.002 | 10.6 | 2.68 |
| Swan River | 1 | 0.002 | <0.002 | 7.59 | 0.823 |
| | 2 | <0.002 | <0.002 | 19.6 | 1.63 |
| | 3 | 0.002 | 0.002 | 13.2 | 0.650 |
| Virden | 1 | 0.004 | <0.002 | 9.02 | 1.21 |
| | 2 | 1.33 | 0.005 | 3.81 | 0.524 |
| Winkler | 1 | <0.002 | <0.002 | 18.8 | 2.94 |
| | 2 | <0.002 | <0.002 | 10.5 | 0.852 |
| | 3 | <0.002 | <0.002 | 7.58 | 1.57 |
| Mean | | 0.035 | 0.002 | 7.38 | 0.83 |

* Site outside of designated spray block; Data not used in calculation of mean or percentages.

TABLE 3: Average concentrations of malathion in lettuce with associated ranges (µg/g).

| Location/Description | Pre-spray | | | | Post-spray | | | |
|---|---|---|---|---|---|---|---|---|
| | Unwashed | | Washed | | Unwashed | | Washed | |
| | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| **First Spray Event** | | | | | | | | |
| Winnipeg | 0.018 | <0.002 - 0.065 | 0.005 | <0.002 - 0.020 | 6.66* | 0.164 - 15.6* | 0.85 | 0.084 - 2.70 |
| Southern Manitoba ** | 0.035 | <0.002 - 1.33 | 0.002 | <0.002 - 0.010 | 7.38 | <0.002 - 24.6 | 0.83 | <0.002 - 2.94 |
| **Second Spray Event** | | | | | | | | |
| Winnipeg | 0.022 | 0.005 - 0.052 | 0.008 | <0.002 - 0.041 | 7.39 | 0.093 - 24.6 | 1.72 | 0.066 - 7.86 |

*Excluding outlier value of 78.4 ug/g.

**Not including City of Winnipeg.

**TABLE 4: Post-spray degradation of malathion in lettuce under field conditions.**

| Site No. | 1 hour | | 2-5 days | | 7 days | | 14 days | |
|---|---|---|---|---|---|---|---|---|
| | UW | W | UW | W | UW | W | UW | W |
| 2 | - | 0.215 | 0.207(5) | 0.116 | 0.007 | - | <0.002 | - |
| 8 | 11.7 | 4.02 | 5.53(2) | 0.753 | 0.061 | 0.024 | 0.016 | 0.008 |
| 10 | 8.80 | 3.24 | 1.74(2) | 0.467 | 0.013 | 0.008 | 0.005 | - |
| 12 | - | 0.584 | 0.090(4) | 0.013 | 0.199 | <0.002 | 0.048 | 0.003 |

( ) Days since malathion spray application.
UW - unwashed sample.
W - washed sample.

TABLE 5. Malathion concentration (µg/g) in unwashed pre and post-spray samples of green onion tops compared with that in unwashed post-spray samples of lettuce from corresponding gardens.

| City/Town | Site No. | Onions | | Lettuce |
|---|---|---|---|---|
| | | Pre-Spray | Post-Spray | Post Spray |
| Altona | 1 | <0.002 | 0.010 | 0.033 |
| Beausejour | 1 | <0.002 | 10.7 | 15.3 |
| Brandon | 3 | 0.005 | 9.69 | 12.3 |
| | 4 | <0.002 | 15.5 | 6.44 |
| Carman | 4 | <0.002 | 0.814 | 14.6 |
| Morden | 2 | <0.002 | 3.75 | - |
| Morris | 1 | <0.002 | 3.55 | 4.36 |
| Portage la Prairie | 1 | <0.002 | 2.67 | 1.69 |
| Selkirk (E) | 1* | <0.002 | 0.303 | 0.180 |
| Stonewall | 1 | 0.004 | 0.219 | 0.372 |
| Virden | 2 | 0.006 | 3.71 | 3.81 |
| Winkler | 2 | <0.002 | 7.27 | 10.50 |
| Winnipeg | 10 | <0.002 | 0.909 | 10.6 |
| | 11* | <0.002 | 0.160 | 0.132 |
| Mean | | 0.003 | 4.90 | |

* Sites outside of prescribed spray block; Data not used in calculation of means or precentages.

TABLE 6. Malathion concentration (µg/g) in unwashed pre- and post-spray samples of strawberries, raspberries and apples.

| Fruit | City/Town | Site No. | Pre-Spray | Post-Spray |
|---|---|---|---|---|
| Strawberries | Carman | 1 | <0.002 | 0.036 |
| | Portage la Prairie | 5 | <0.002 | 0.036 |
| | East Selkirk | 2 | <0.002 | 0.228 |
| | | 5 | <0.002 | 0.706 |
| | | Mean | 0.002 | 0.251 |
| Raspberries | Brandon | 1 | <0.002 | 0.444 |
| | | 3 | <0.002 | 0.155 |
| | Carman | 4 | <0.002 | 0.053 |
| | Portage la Prairie | 1 | <0.002 | 0.129 |
| | Virden | 2 | <0.002 | 0.444 |
| | Winkler | 2 | - | 0.298 |
| | | Mean | 0.002 | 0.254 |
| Apples | Altona | 3 | <0.002 | 0.002 |
| | Carman | 2 | <0.002 | 0.083 |
| | Stonewall | 3 | <0.002 | 0.060 |
| | Winkler | 2 | <0.002 | 0.109 |
| | Winnipeg | 2 | <0.002 | 0.005 |
| | | Mean | 0.002 | 0.052 |

ACKNOWLEGEMENTS

We wish to thank all homeowners and strawberry growers who participated in this study by willingly providing permission for access and sampling on their properties. We also express our gratitude to the many individuals who assisted by identifying/contacting residents who were willing to participate and to the Manitoba Cooperative Dairy in Dauphin and the Elkhorn Ranch Motel in Riding Mountain National Park for allowing us to store samples in their freezers.

We are grateful to the Pesticide Research Laboratory, Department of Soil Science, University of Manitoba, who on request, generously apprised us of their information base with respect to sample handling and storage as well as analytical technology. That information assisted in the development of methods used in this vegetable and fruit monitoring program. We also wish to thank the Pesticide Research Laboratory for providing interim freezer storage for the samples.

In addition, we acknowledge the contribution of the Fresh Water Institute, Fisheries and Oceans, Environment Canada, who provided freezer storage facilities.

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## APPENDIX 1

Maps of 15 cities and towns in Southern Manitoba showing sample site locations and the approximate position of aerial spray flight lines.

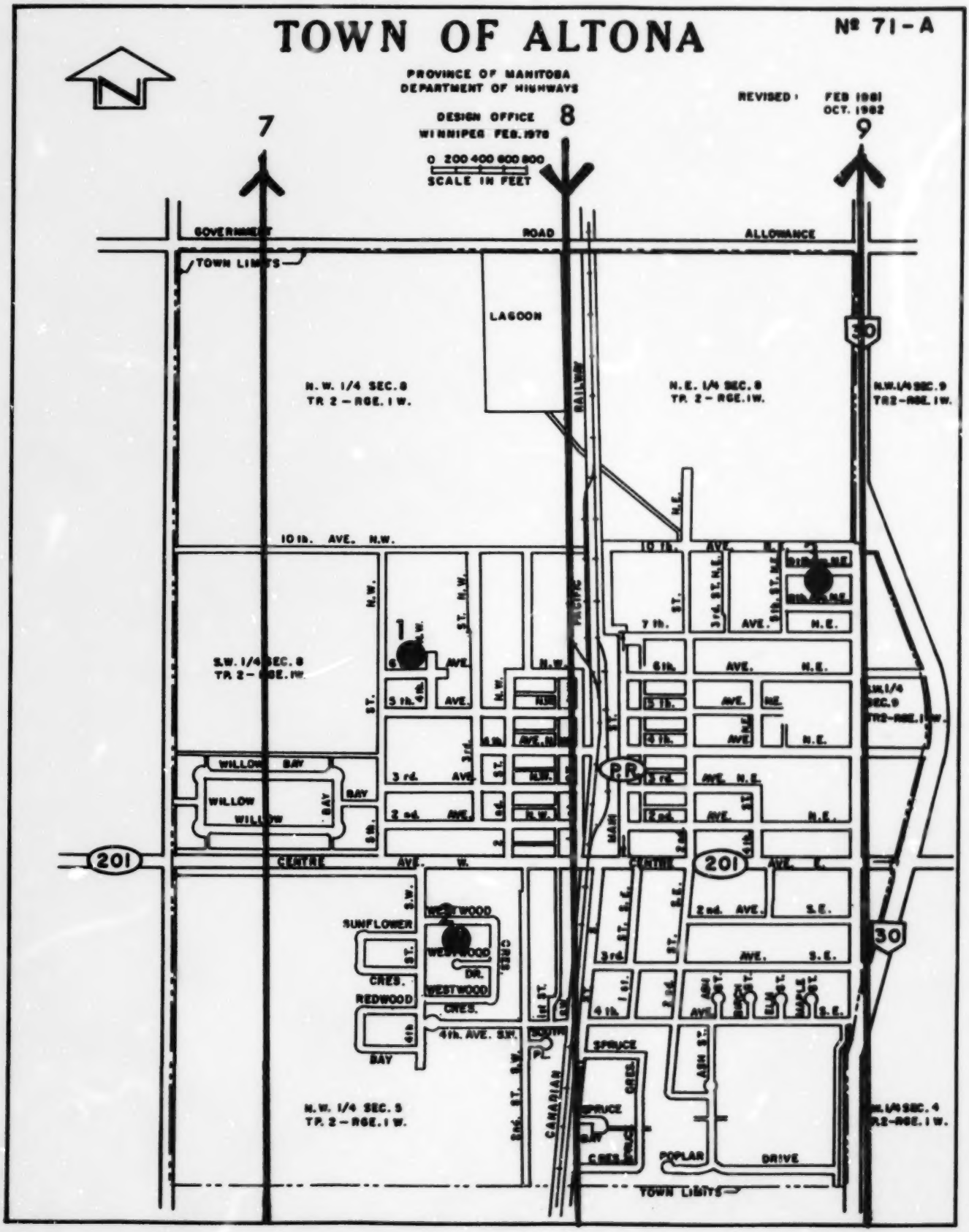
# MAP LEGEND

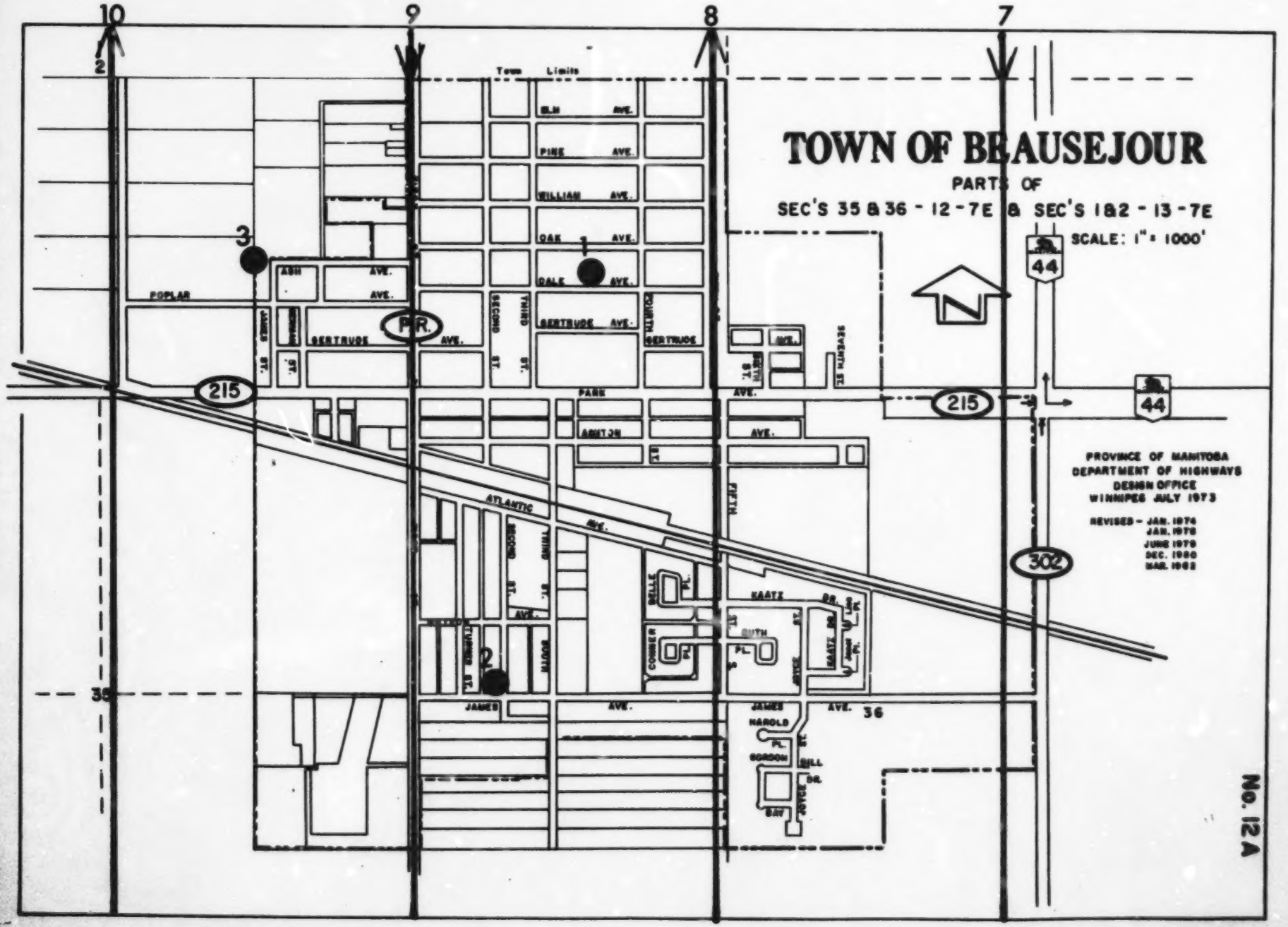
- AERIAL SPRAY FLIGHT LINES

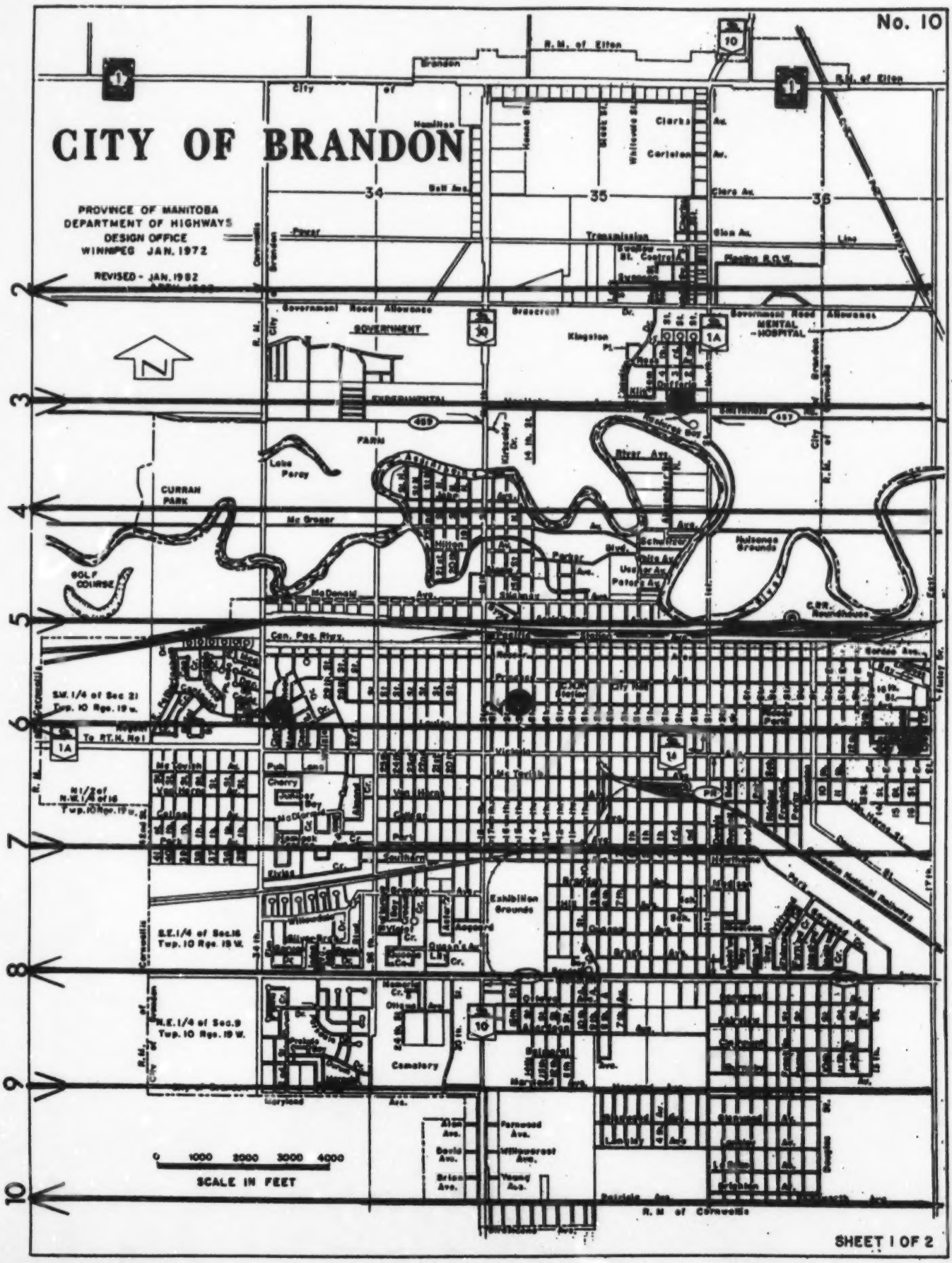
● - SAMPLE LOCATIONS

# TOWN OF ALTONA

Nº 71-A

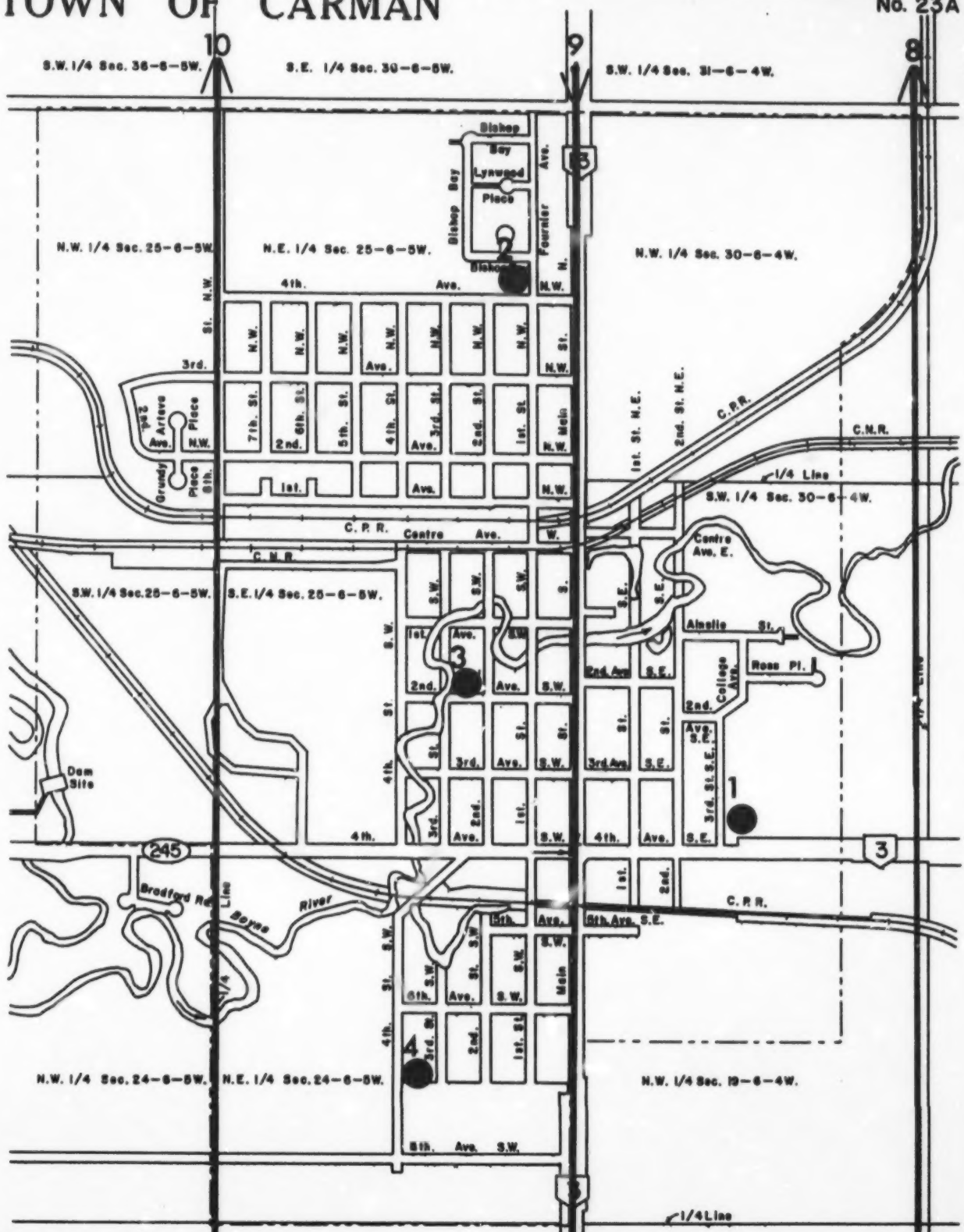



10
9
8
7
2
3
35
36
Town Limits
ELM AVE.
PINE AVE.
WILLIAM AVE.
OAK AVE.
DALE AVE.
GERTRUDE AVE.
ASH AVE.
POPLAR
PR.
215
44
FIRST ST.
SECOND ST.
THIRD ST.
FOURTH ST.
PARK
ASHTON
ATLANTIC AVE.
JAMES AVE.
HAROLD PL.
GORDON
BELLE PL.
CONNER PL.
KAATZ DR.
KAATZ PL.
RIVER
SMITH
SKEWSEN ST.
302
TOWN OF BEAUSEJOUR
PARTS OF
SEC'S 35 & 36 - 12 - 7E & SEC'S 1 & 2 - 13 - 7E
SCALE: 1" = 1000'
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
WINNIPEG JULY 1973
REVISED - JAN. 1974
JAN. 1978
JUNE 1979
DEC. 1980
MAR. 1982
No. 12A


No. 10
CITY OF BRANDON
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
WINNIPEG JAN. 1972
REVISED - JAN. 1982
R.M. of Elton
City of Brandon
R.M. of Cornwallis
Government Road Allowance
GOVERNMENT
MENTAL HOSPITAL
FARM
CURRAN PARK
Lake Percy
GOLF COURSE
Can. Pac. Rlys.
C.P.R. Roundhouse
Exhibition Grounds
Cemetery
Hilltop
Parker
McDonald
McGregor
Victoria
Princess
Rosser
Richmond
Louise
Pacific
Saskatchewan
Kingston Pl.
Clarke Av.
Carleton Av.
Glen Av.
River Av.
Rosser Ave.
Hotsonga Grounds
Transmission
Meeting R.O.W.
Brookcrest Dr.
Crescent Dr.
Parkwood Ave.
Willowcrest Ave.
Young Ave.
Allen Ave.
David Ave.
Brian Ave.
Patricia Ave.
Kirkcaldy Ave.
Maryland
Cherry
Elkhorn Cr.
Assiniboine River
S.W. 1/4 of Sec 21 Twp. 10 Rge. 19 W.
N1/2 of N.W. 1/4 of 16 Twp. 10 Rge. 19 W.
S.E. 1/4 of Sec. 16 Twp. 10 Rge. 19 W.
N.E. 1/4 of Sec. 9 Twp. 10 Rge. 19 W.
To RT.H. No. 1
0 1000 2000 3000 4000
SCALE IN FEET
R.M. of Cornwallis
SHEET 1 OF 2

# TOWN OF CARMAN

No. 23A




PART OF SEC'S. 24 & 25-6-5W.
19 & 30-6-4W.

SCALE 200 0 200 400 600 800 1000

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
DESIGN OFFICE
WINNIPEG, DEC. 1980

N

REVISED
JULY 1981
APRIL 1982

No. 21 A

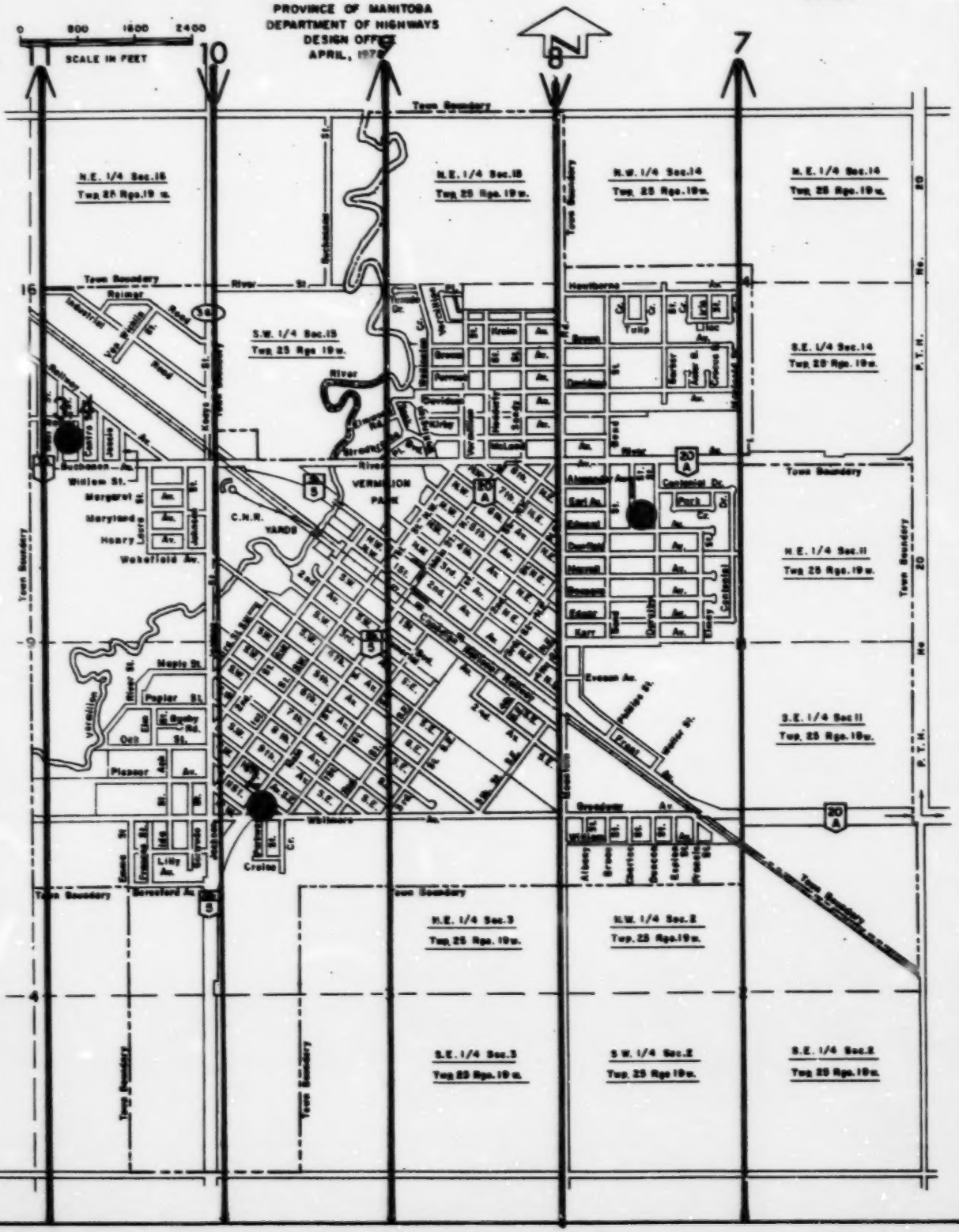
# TOWN OF DAUPHIN

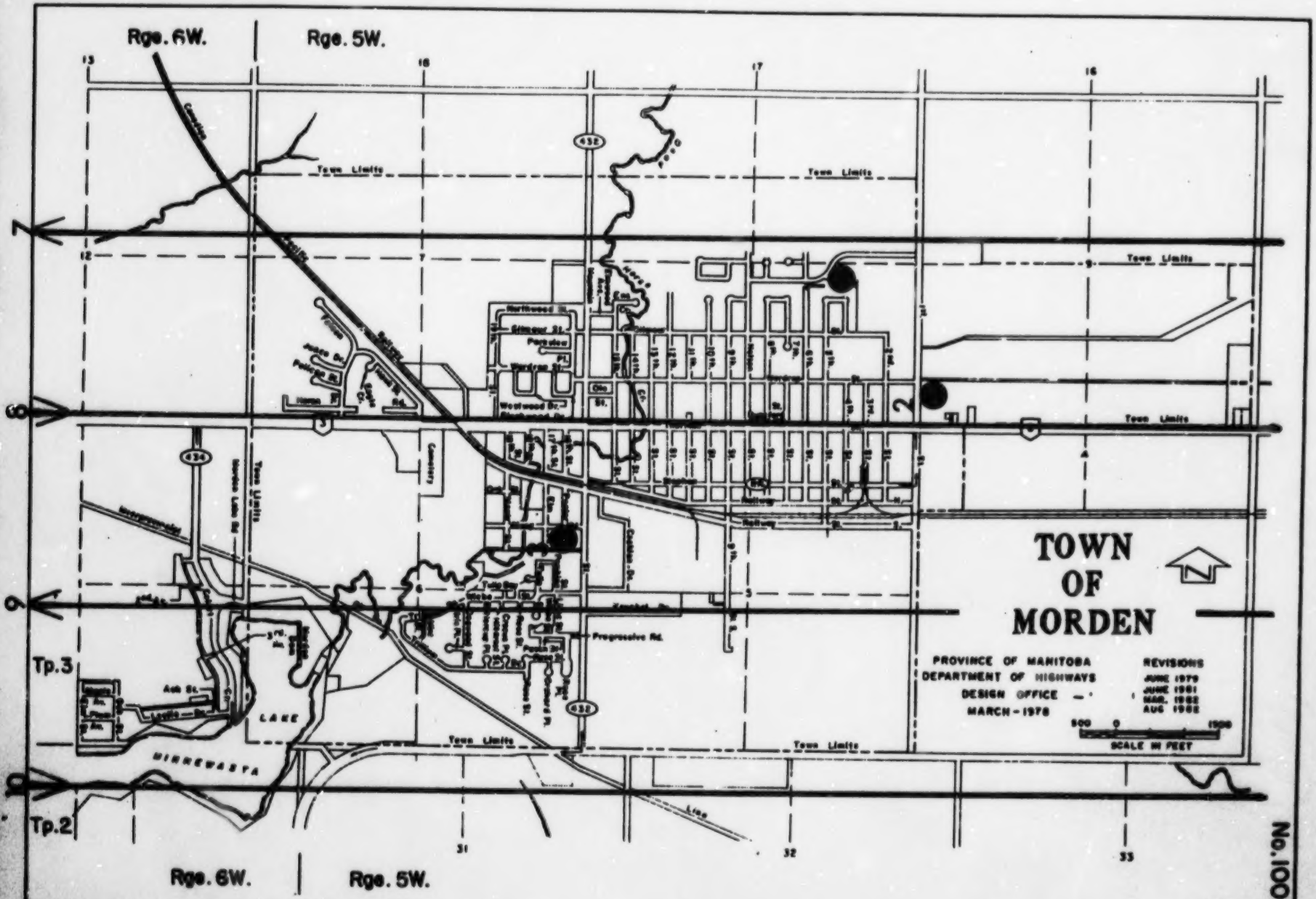
IN SEC'S. 10, 11 AND IN PARTS OF SEC'S. 2, 3, 4, 9, 14, 15 AND 16

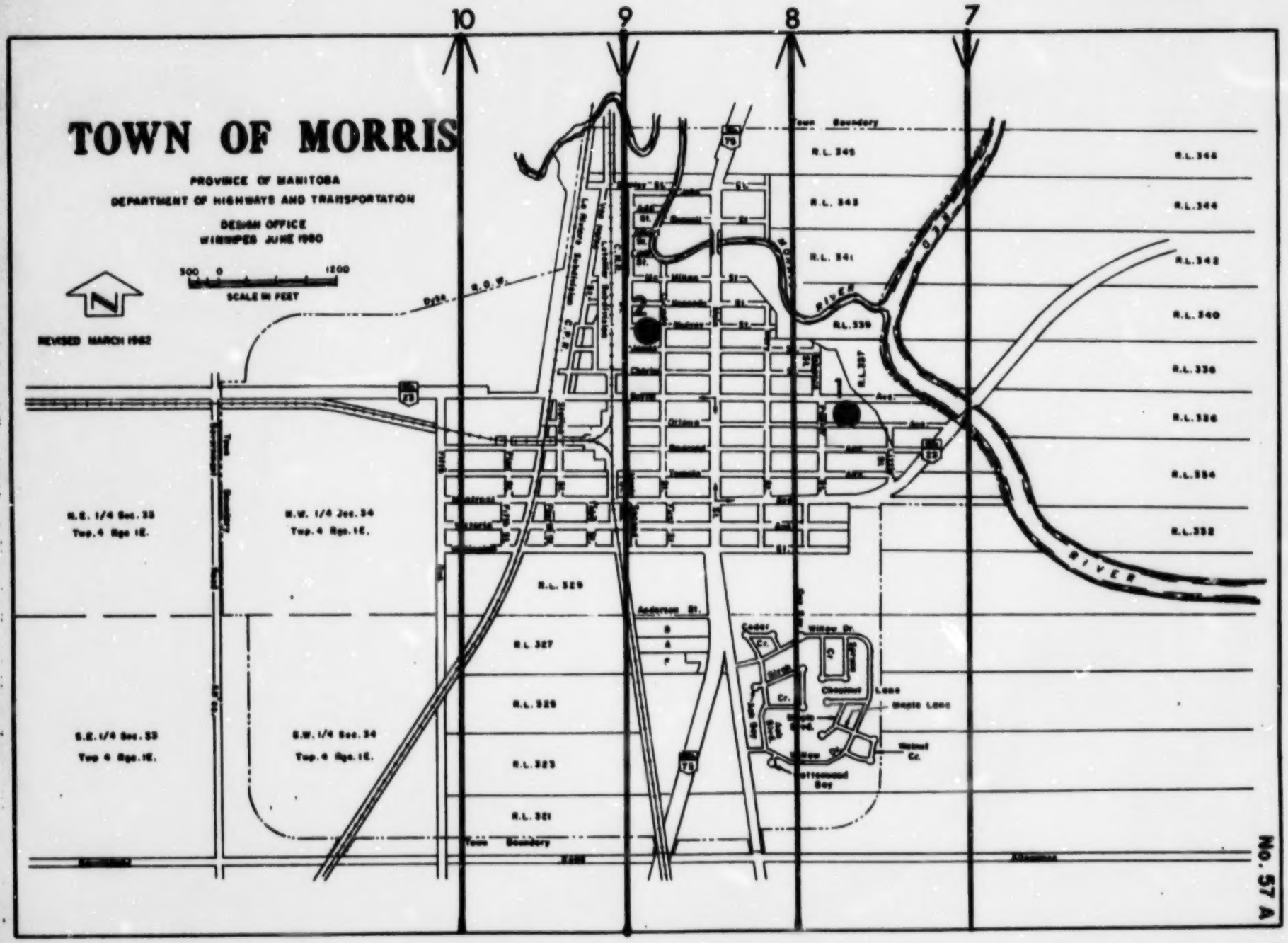
ALL IN TWP. 25 RGE. 19 W

REVISIONS:- NOV. 1978
JULY 1980

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
APRIL, 1978




Rge. 6W.
Rge. 5W.
Town Limits
Progressive Rd.
Tp.3
Tp.2
LAKE
MINNEWASTA
Rge. 6W.
Rge. 5W.
TOWN
OF
MORDEN
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
MARCH - 1978
REVISIONS
JUNE 1979
JUNE 1981
MAR. 1982
AUG 1982
SCALE IN FEET
No. 100A

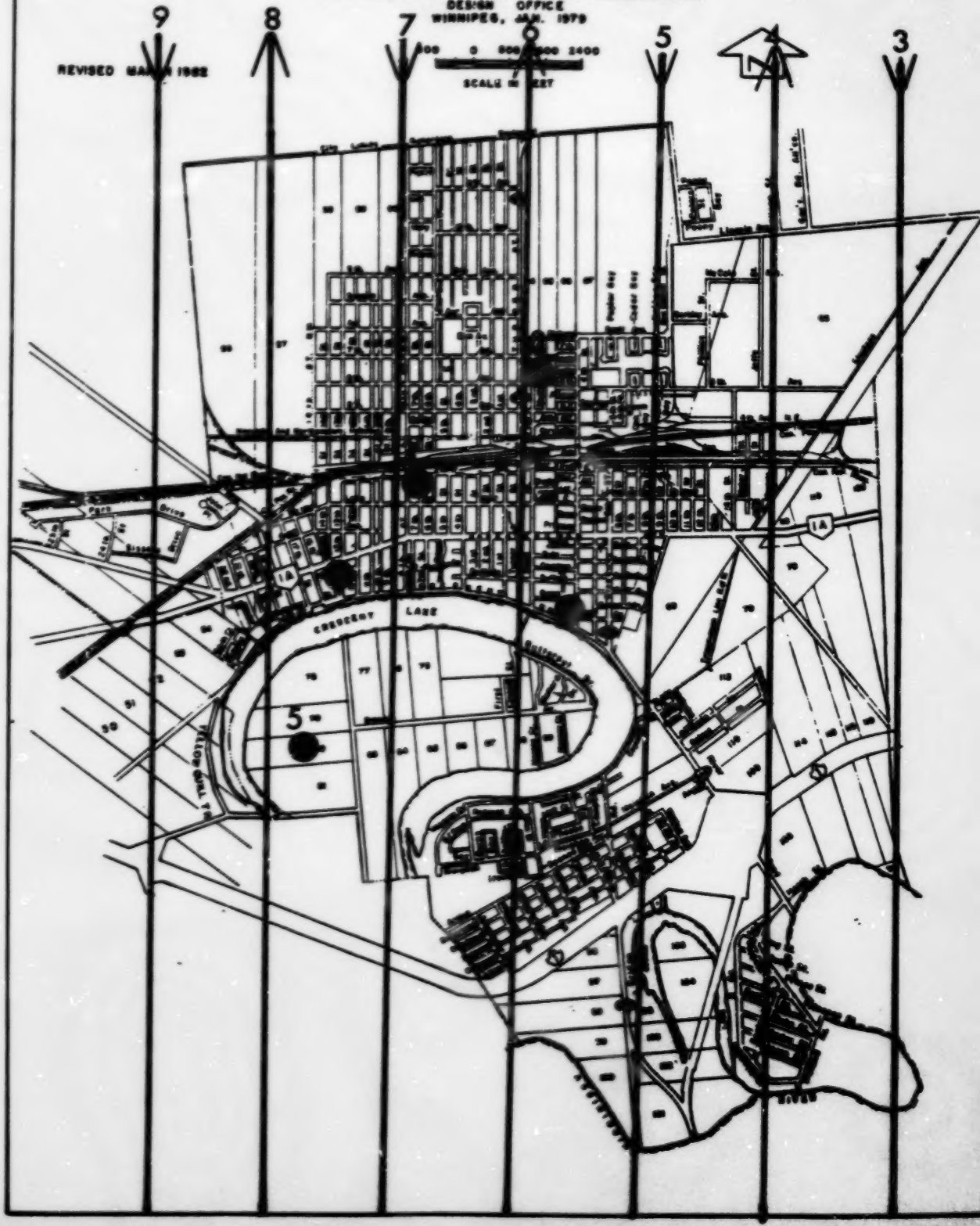

10
9
8
7
TOWN OF MORRIS
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
DESIGN OFFICE
WINNIPEG JUNE 1980
300 0 1200
SCALE IN FEET
N
REVISED MARCH 1982
Town Boundary
R.L. 345
R.L. 343
R.L. 341
R.L. 339
R.L. 337
R.L. 329
R.L. 327
R.L. 325
R.L. 323
R.L. 321
R.L. 346
R.L. 344
R.L. 342
R.L. 340
R.L. 338
R.L. 336
R.L. 334
R.L. 332
RIVER
N.E. 1/4 Sec. 33
Twp. 4 Rge. 1E.
N.W. 1/4 Sec. 34
Twp. 4 Rge. 1E.
S.E. 1/4 Sec. 33
Twp. 4 Rge. 1E.
S.W. 1/4 Sec. 34
Twp. 4 Rge. 1E.
Anderson St.
Cedar Cr.
Willow Dr.
Chestnut Lane
Maple Lane
Walnut Cr.
Cottonwood Bay
No. 57 A

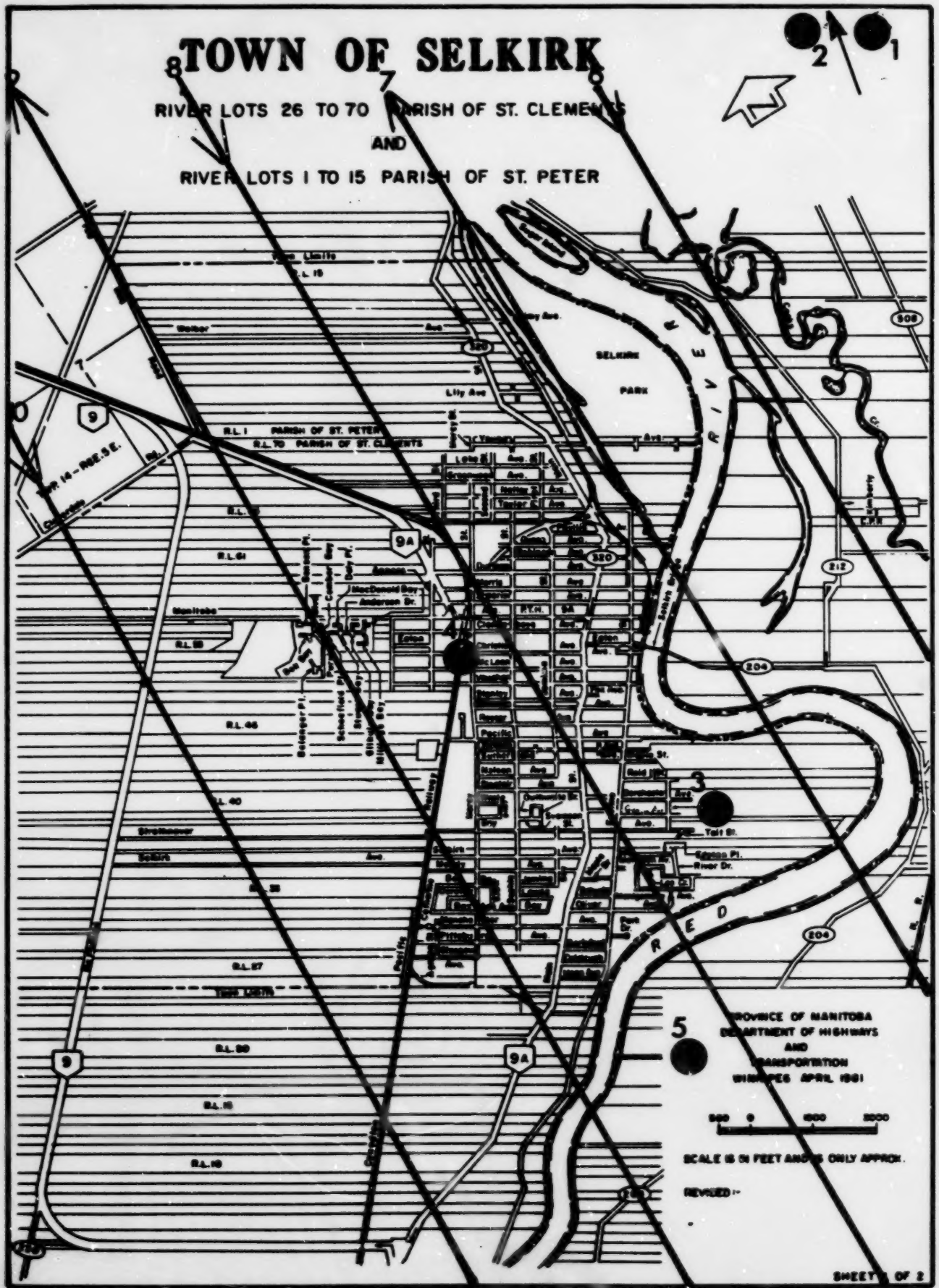
# CITY OF PORTAGE LA PRAIRIE

No. 6

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
DESIGN OFFICE
WINNIPEG, MAR. 1979

REVISED MARCH 1982




TOWN OF SELKIRK
RIVER LOTS 26 TO 70 PARISH OF ST. CLEMENTS
AND
RIVER LOTS 1 TO 15 PARISH OF ST. PETER
RED RIVER
SELKIRK PARK
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
AND
TRANSPORTATION
WINNIPEG APRIL 1961
SCALE IS IN FEET AND IS ONLY APPROX.
REVISED:-
SHEET 1 OF 2

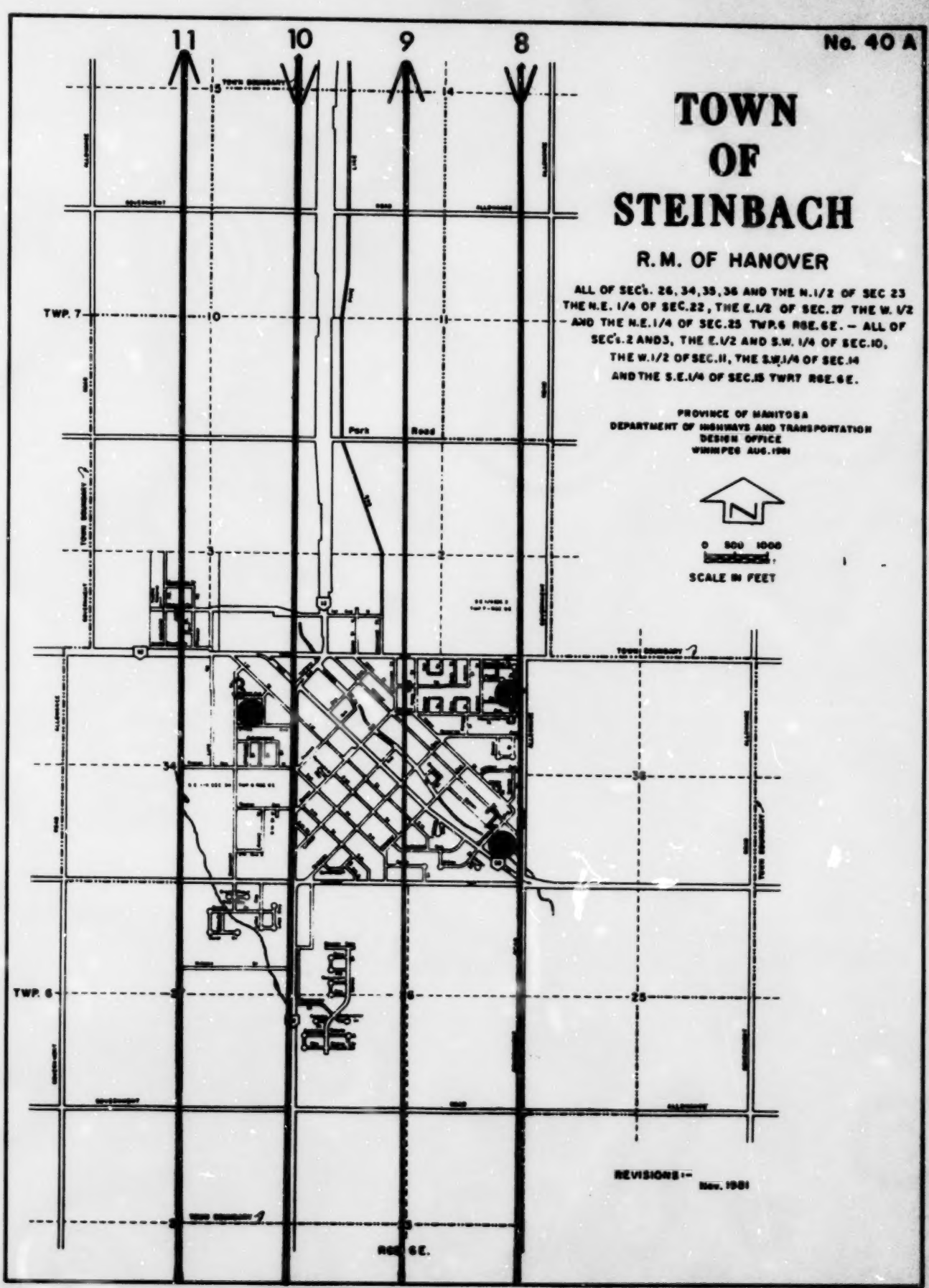
No. 40 A

# TOWN OF STEINBACH

## R.M. OF HANOVER

ALL OF SEC's. 26, 34, 35, 36 AND THE N.1/2 OF SEC 23 THE N.E. 1/4 OF SEC.22, THE E.1/2 OF SEC. 27 THE W. 1/2 AND THE N.E.1/4 OF SEC.25 TWP.6 RGE.6E. – ALL OF SEC's.2 AND3, THE E.1/2 AND S.W. 1/4 OF SEC.10, THE W.1/2 OF SEC.11, THE S.W.1/4 OF SEC.14 AND THE S.E.1/4 OF SEC.15 TWP.7 RGE.6E.

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
DESIGN OFFICE
WINNIPEG AUG. 1981



No. 75 A

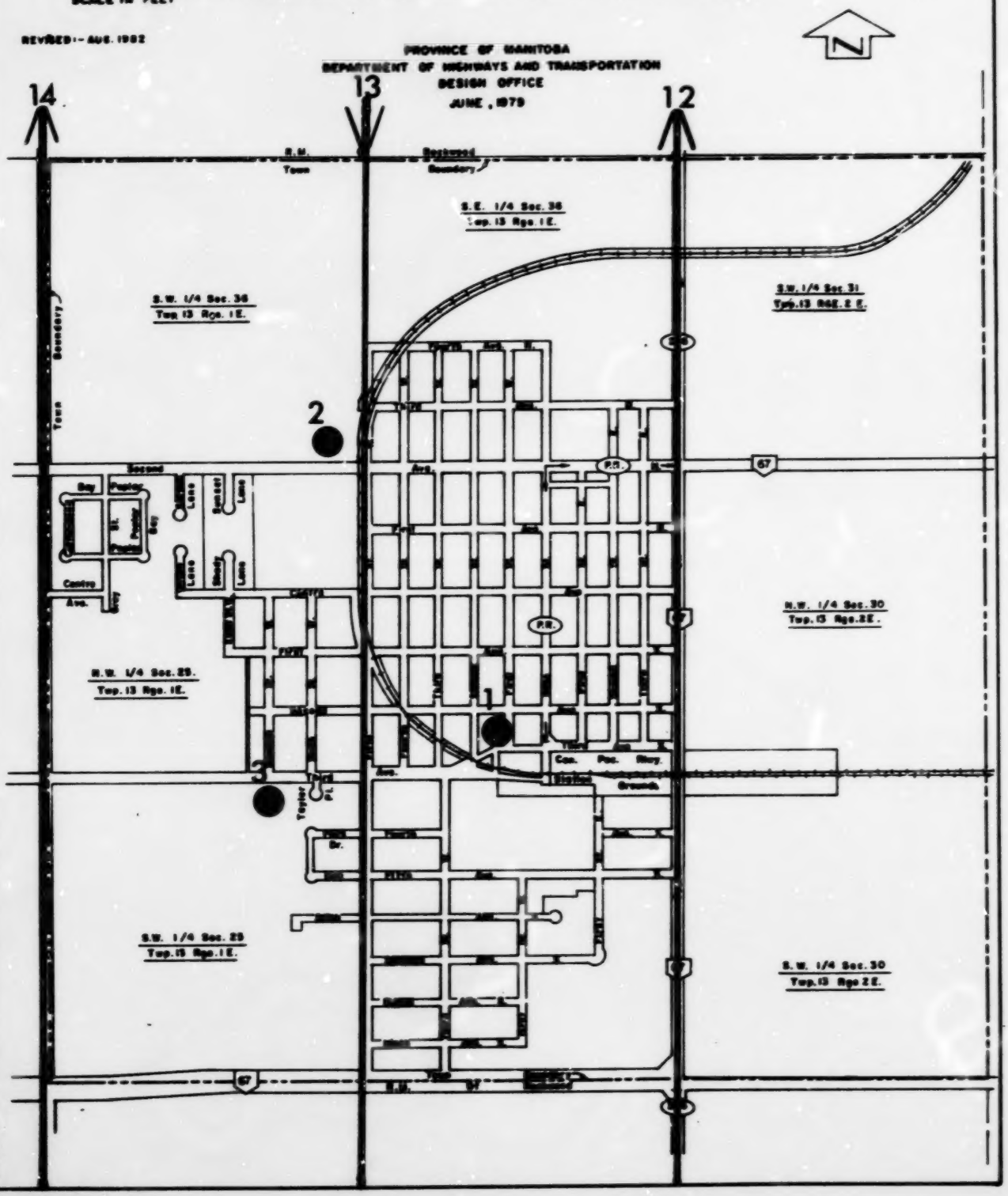
# TOWN OF STONEWALL

ALL OF SEC. 25 AND S. 1/2 SEC. 36 TWP. 13 RGE. 1 E
W. 1/2 SEC 30 AND S.W. 1/4 SEC. 31 TWP. 13 RGE. 2 E.

0 500 1000
SCALE IN FEET

REVISED:- AUG. 1982

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
DESIGN OFFICE
JUNE, 1979



No. 103 B

# TOWN OF SWAN RIVER

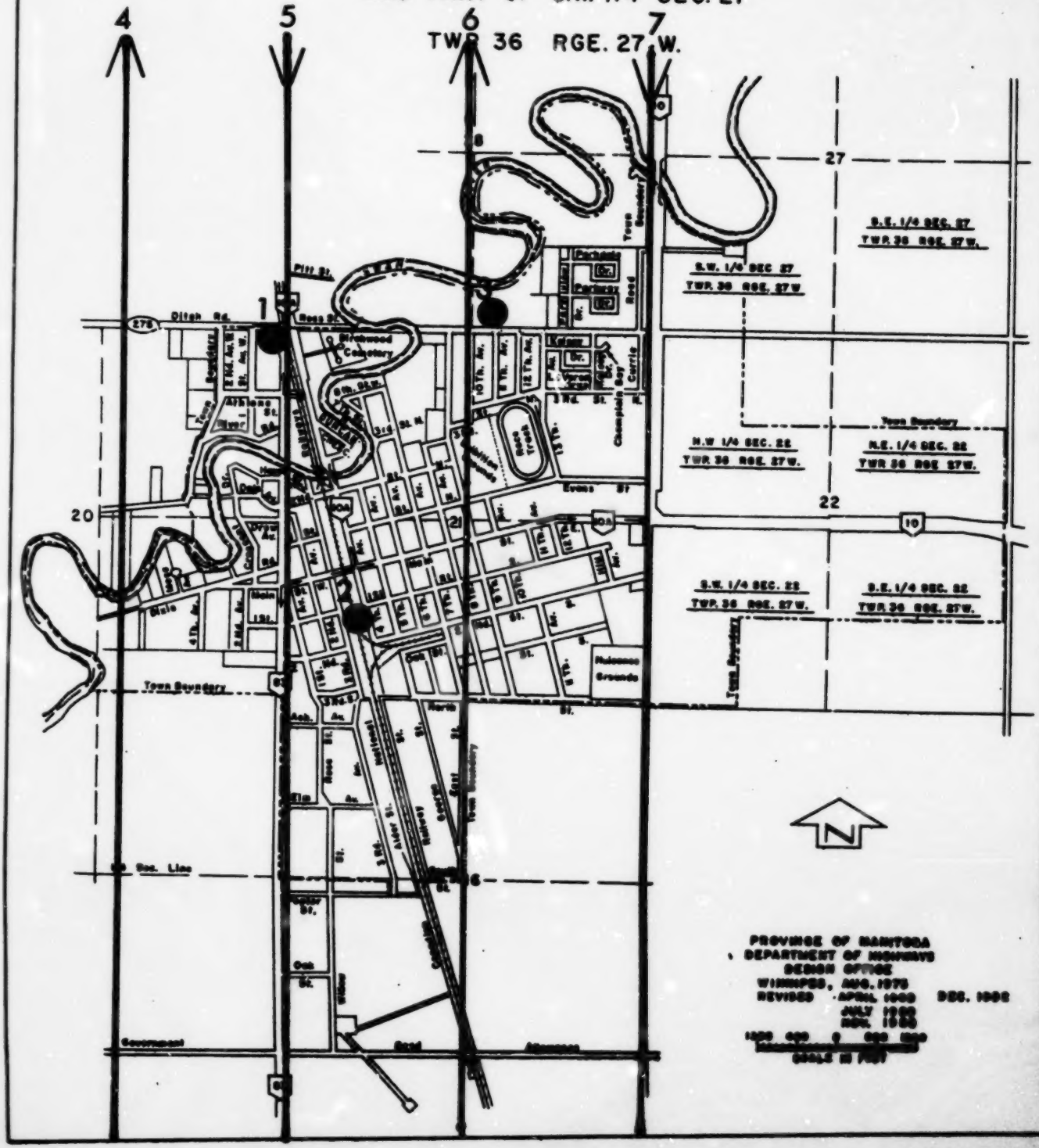
IN

SEC. 21, PART OF E. 1/2 SEC. 20

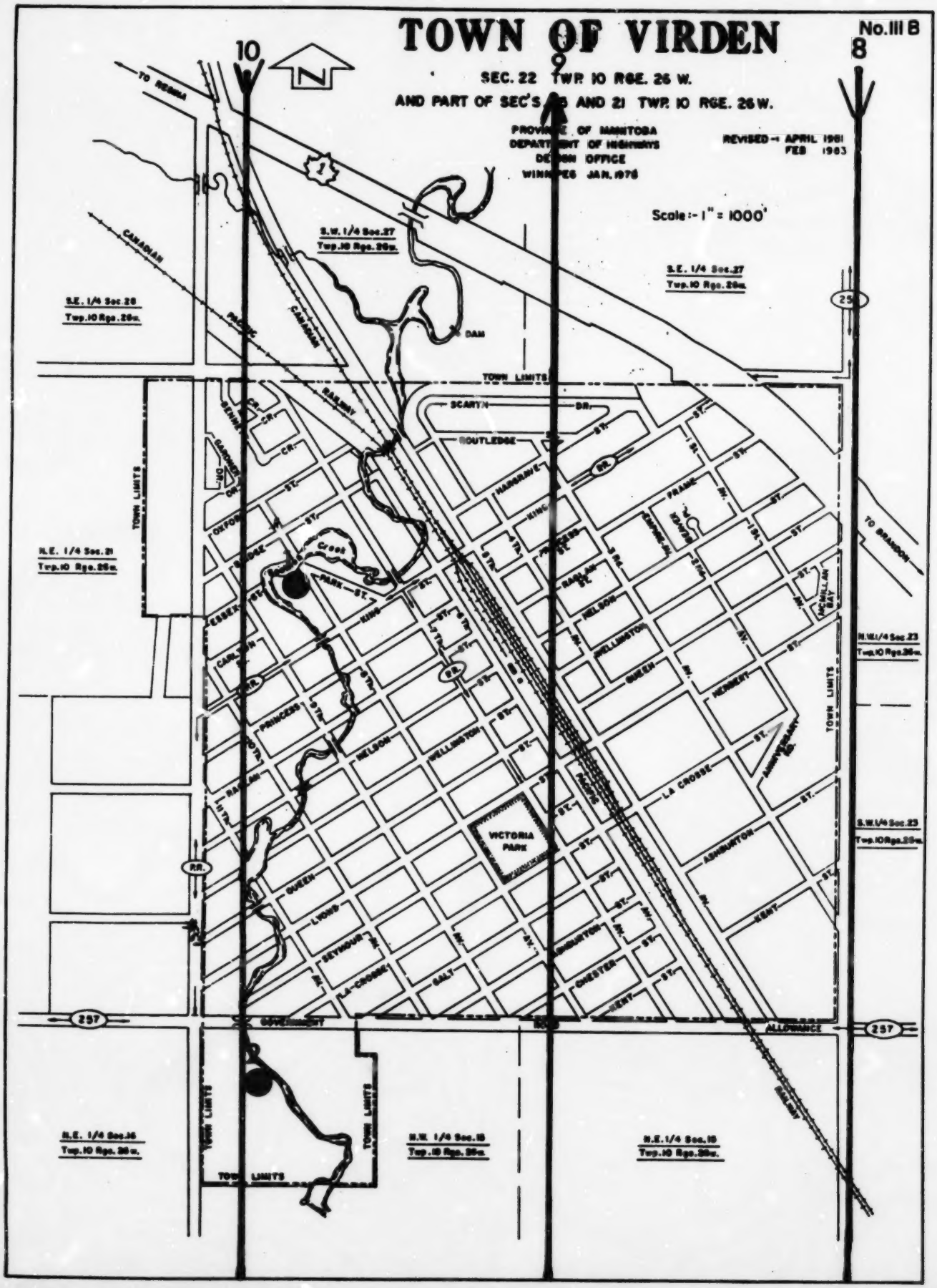
N.W. 1/4 SEC. 16, PART OF SEC. 22

AND PART OF S.W. 1/4 SEC. 27

TWP. 36 RGE. 27 W.



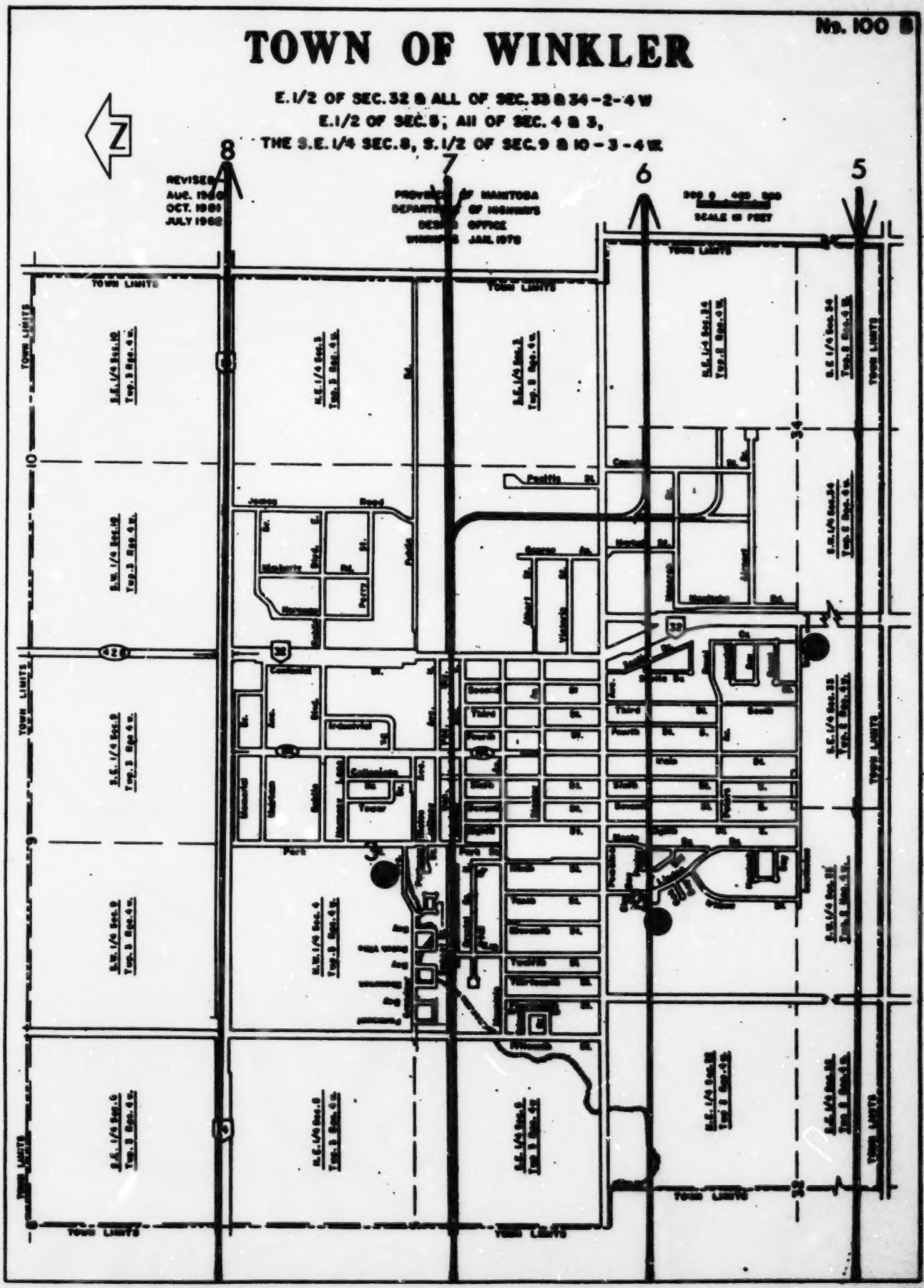

PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
WINNIPEG, AUG. 1970
REVISED APRIL 1972 DEC. 1972
JULY 1973
NOV. 1973


TOWN OF VIRDEN
No. III B
SEC. 22 TWP. 10 RGE. 26 W.
AND PART OF SEC'S 15 AND 21 TWP. 10 RGE. 26 W.
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
WINNIPEG JAN. 1978
REVISED — APRIL 1981
FEB 1983
Scale:- 1" = 1000'
10
9
8
N
TO REGINA
CANADIAN PACIFIC RAILWAY
S.W. 1/4 Sec. 27 Twp. 10 Rge. 26w.
S.E. 1/4 Sec. 27 Twp. 10 Rge. 26w.
S.E. 1/4 Sec. 28 Twp. 10 Rge. 26w.
DAM
TOWN LIMITS
SCARTH DR.
ROUTLEDGE
HARRIAN E.
KING
PRINCESS ST.
RAILWAY ST.
FRANK
MELBOURNE
WELLINGTON
QUEEN
HENRIETT
McMILLAN BAY
TO BRANDON
N.E. 1/4 Sec. 21 Twp. 10 Rge. 26w.
OXFORD
ESSEX
CARLTON
PARK ST.
Cross
PRINCESS
NELSON
WELLINGTON
QUEEN
LIVIUS
SEYMOUR
LA CROSSE
SALT
VICTORIA PARK
LA CROSSE
ASHBURTON
KENT
CHESTER
ALLOWANCE
257
RR.
N.W.1/4 Sec. 23 Twp. 10 Rge. 26w.
S.W.1/4 Sec. 23 Twp. 10 Rge. 26w.
N.E. 1/4 Sec. 16 Twp. 10 Rge. 26w.
N.W. 1/4 Sec. 15 Twp. 10 Rge. 26w.
N.E. 1/4 Sec. 15 Twp. 10 Rge. 26w.

No. 100 B

# TOWN OF WINKLER

E.1/2 OF SEC. 32 & ALL OF SEC. 33 & 34 - 2 - 4 W
E.1/2 OF SEC. 5; ALL OF SEC. 4 & 3,
THE S.E. 1/4 SEC. 8, S.1/2 OF SEC. 9 & 10 - 3 - 4 W.


N
8
7
6
5
REVISED
AUG. 1960
OCT. 1961
JULY 1962
PROVINCE OF MANITOBA
DEPARTMENT OF HIGHWAYS
DESIGN OFFICE
JAN. 1970
SCALE IN FEET
TOWN LIMITS
Jubilee Road
Public
Park
Centennial
Collegiate
Theatre
Post Office
Fire Hall
Arena
Curling Rink
Swimming Pool
Tennis Courts
Ball Diamonds
Cemetery
Creek
Railway
Grain Elevators
Lumber Yard
Implement Dealer
Garage
Hotel
Bank
Motel
Restaurant
Service Station
Bus Depot
Laundry
Dry Cleaning
Drug Store
Hardware
Furniture
Clothing
Shoes
Jewellery
Variety
Supermarket
Grocery
Bakery
Meat Market
Barber Shop
Beauty Parlour
Photography
Insurance
Real Estate
Law Office
Medical Clinic
Dental Clinic
Optometrist
Veterinary
Funeral Home
Flower Shop
Florist
Radio & TV
Appliances
Sporting Goods
Toys
Books
Stationery
Office Supplies
Office Equipment
Photo Supplies
Gifts
Cards
Souvenirs
Antiques
Art Gallery
Music
Musical Instruments
Records
Tapes
Pets
Pet Supplies
Nursery
Seeds
Fertilizer
Chemicals
Paint
Wallpaper
Floor Coverings
Curtains
Drapes
Linens
Towels
Blankets
Quilts
Pillows
Mattresses
Beds
Chairs
Tables
Desks
Lamps
Clocks
Mirrors
Pictures
Frames
Glass
Mirrors
Windows
Doors
Roofing
Siding
Insulation
Plumbing
Heating
Electrical
Lighting
Fixtures
Wiring
Switches
Outlets
Meters
Transformers
Poles
Wires
Cables
Antennas
Towers
Guy Wires
Anchors
Concrete
Blocks
Bricks
Stone
Gravel
Sand
Asphalt
Paving
Curbs
Gutters
Sidewalks
Driveways
Parking
Signs
Billboards
Lights
Traffic Lights
Crosswalks
Pedestrian
Bicycle
Motorcycle
Car
Truck
Bus
Trailer
Camper
Boat
Canoe
Kayak
Raft
Life Jacket
Paddle
Oar
Motor
Engine
Fuel
Oil
Grease
Filter
Spark Plug
Battery
Tire
Wheel
Axle
Brake
Clutch
Transmission
Gear
Chain
Sprocket
Pedal
Handlebar
Seat
Frame
Fork
Spoke
Rim
Hub
Reflector
Light
Horn
Bell
Basket
Rack
Trailer Hitch
Ball
Coupler
Safety Chain
Jack
Spare Tire
Tool Box
Wrench
Screwdriver
Hammer
Pliers
Saw
Drill
Bit
Chisel
File
Sandpaper
Level
Square
Tape Measure
Ruler
Pencil
Pen
Eraser
Sharpener
Notebook
Paper
Envelope
Stamp
Mailbox
Letter
Package
Parcel
Post Office
Postal Code
Address
Name
Phone
Telephone
Directory
Yellow Pages
White Pages
Emergency
Police
Fire
Ambulance
Hospital
Doctor
Nurse
Patient
Medicine
Pharmacy
Prescription
Dosage
Pill
Tablet
Capsule
Liquid
Ointment
Bandage
Gauze
Tape
Scissors
Thermometer
Blood Pressure
Pulse
Heart
Lung
Kidney
Liver
Stomach
Intestine
Bladder
Brain
Spinal Cord
Nerve
Muscle
Bone
Skeleton
Skull
Rib
Spine
Pelvis
Leg
Arm
Hand
Foot
Finger
Toe
Eye
Ear
Nose
Mouth
Tooth
Tongue
Throat
Neck
Shoulder
Chest
Abdomen
Back
Hip
Knee
Ankle
Wrist
Elbow
Skin
Hair
Nail
Blood
Vein
Artery
Capillary
Cell
Tissue
Organ
System
Body
Health
Disease
Infection
Virus
Bacteria
Germ
Immune
Vaccine
Injection
Needle
Syringe
Medicine
Drug
Alcohol
Tobacco
Smoke
Cancer
Tumor
Growth
Cure
Treatment
Therapy
Surgery
Operation
Anesthetic
Recovery
Rehabilitation
Exercise
Diet
Nutrition
Vitamin
Mineral
Protein
Carbohydrate
Fat
Calorie
Weight
Height
Age
Birth
Death
Life
Time
Day
Night
Morning
Afternoon
Evening
Week
Month
Year
Season
Spring
Summer
Autumn
Winter
Weather
Rain
Snow
Wind
Storm
Flood
Drought
Heat
Cold
Temperature
Thermometer
Barometer
Humidity
Pressure
Cloud
Sun
Moon
Star
Planet
Earth
Sky
Space
Universe
Gravity
Force
Energy
Power
Work
Machine
Lever
Pulley
Wheel
Axle
Screw
Wedge
Inclined Plane
Simple Machine
Compound Machine
Engine
Motor
Turbine
Generator
Electricity
Magnetism
Electromagnetism
Induction
Current
Voltage
Resistance
Ohm
Ampere
Volt
Watt
Joule
Coulomb
Farad
Henry
Tesla
Weber
Maxwell
Gauss
Oersted
Ampere
Faraday
Lenz
Ohm
Kirchhoff
Thevenin
Norton
Superposition
Reciprocity
Maximum Power Transfer
Impedance
Admittance
Reactance
Susceptance
Conductance
Resistance
Capacitance
Inductance
Mutual Inductance
Coupling
Transformer
Ideal Transformer
Real Transformer
Autotransformer
Isolation Transformer
Step-up Transformer
Step-down Transformer
Three-phase
Single-phase
Delta
Wye
Star
Mesh
Node
Branch
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Tree
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Resistor
Capacitor
Inductor
Diode
Transistor
Amplifier
Oscillator
Filter
Rectifier
Regulator
Switch
Relay
Fuse
Circuit Breaker
Ground
Earth
Shield
Cable
Wire
Connector
Terminal
Plug
Socket
Jack
Adapter
Converter
Inverter
Modulator
Demodulator
Multiplexer
Demultiplexer
Encoder
Decoder
Transmitter
Receiver
Transceiver
Antenna
Waveguide
Fiber Optic
Laser
LED
Photodiode
Solar Cell
Battery
Fuel Cell
Capacitor
Supercapacitor
Ultracapacitor
Inductor
Coil
Core
Winding
Turn
Primary
Secondary
Tertiary
Leakage
Saturation
Hysteresis
Eddy Current
Skin Effect
Proximity Effect
Corona
Arc
Spark
Breakdown
Dielectric
Insulator
Conductor
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Resistivity
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Permeability
Susceptibility
Polarization
Magnetization
Hysteresis
Curie Temperature
Ferromagnetism
Paramagnetism
Diamagnetism
Antiferromagnetism
Ferrimagnetism
Spin
Orbital
Electron
Proton
Neutron
Nucleus
Atom
Molecule
Ion
Plasma
Gas
Liquid
Solid
Crystal
Lattice
Band
Gap
Valence
Conduction
Hole
Doping
N-type
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PN Junction
Depletion Region
Forward Bias
Reverse Bias
Breakdown
Zener
Avalanche
Tunnel
Schottky
Varactor
Varistor
Thermistor
Photoresistor
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Photovoltaic
Photoconductive
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Night Vision
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X-ray
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Scintillation
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Amplifier
Transceiver
Antenna
Satellite
Orbit
Geostationary
Polar
Low Earth Orbit
Medium Earth Orbit
Geosynchronous
Transponder
Uplink
Downlink
Ground Station
Mission Control
Launch
Rocket
Booster
Payload
Fairing
Stage
Propellant
Oxidizer
Fuel
Thrust
Specific Impulse
Delta-v
Trajectory
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Landing
Recovery
Reusable
Expendable
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Thermal Control
Radiation Shielding
Micrometeoroid
Orbital Debris
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Observatory
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Asteroid
Comet
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Impact
Crater
Regolith
Ice
Water
Oxygen
Hydrogen
Carbon Dioxide
Methane
Ammonia
Nitrogen
Helium
Argon
Neon
Krypton
Xenon
Radon
Noble Gas
Halogen
Alkali Metal
Alkaline Earth Metal
Transition Metal
Rare Earth
Actinide
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Metalloid
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Radioactive
Decay
Half-life
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Beta
Gamma
Neutrino
Antimatter
Positron
Antiproton
Antineutron
Annihilation
Pair Production
Bremsstrahlung
Cherenkov
Synchrotron
Cyclotron
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Spatial Database
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Remote Sensing
Satellite Imagery
Aerial Photography
LiDAR
Radar
Sonar
Seismic
Gravity
Magnetic
Electromagnetic
Resistivity
Induced Polarization
Ground Penetrating Radar
Borehole Logging
Well Testing
Hydrology
Groundwater
Aquifer
Well
Pump
Pipeline
Reservoir
Dam
Irrigation
Drainage
Flood Control
Water Treatment
Wastewater
Sewage
Septic System
Landfill
Recycling
Composting
Hazardous Waste
Radioactive Waste
Nuclear Waste
Environmental Impact
Sustainability
Renewable Energy
Solar Energy
Wind Energy
Hydroelectric
Geothermal
Biomass
Biofuel
Fossil Fuel
Coal
Oil
Natural Gas
Petroleum
Refinery
Pipeline
Tanker
Offshore
Drilling
Rig
Platform
Subsea
Riser
Blowout Preventer
Mud
Cement
Casing
Tubing
Packer
Perforation
Fracturing
Acidizing
Production
Enhanced Oil Recovery
Steam Injection
Carbon Dioxide Injection
Water Flooding
Gas Lift
Artificial Lift
Pump Jack
Submersible Pump
Progressing Cavity Pump
Electric Submersible Pump
Gas Compressor
Separator
Dehydrator
Sweetening
Flare
Vent
Emission
Pollution
Air Quality
Water Quality
Soil Contamination
Remediation
Monitoring
Sensor
Data Logger
Telemetry
Wireless
Bluetooth
Wi-Fi
Cellular
Satellite Communication
Radio
Microwave
Fiber Optic
Ethernet
USB
Serial
Parallel
Interface
Protocol
Standard
Specification
Testing
Calibration
Certification
Quality Control
Quality Assurance
Inspection
Audit
Documentation
Report
Presentation
Publication
Patent
Trademark
Copyright
License
Contract
Agreement
Negotiation
Procurement
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Sale
Invoice
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Profit
Loss
Tax
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Risk
Safety
Security
Emergency
Evacuation
Fire
Explosion
Accident
Injury
Fatality
Training
Education
Research
Development
Innovation
Technology
Engineering
Science
Mathematics
Physics
Chemistry
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Geology
Astronomy
Meteorology
Oceanography
Ecology
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Milestone
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Allocation
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Responsibility
Authority
Decision
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Solution
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Implementation
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Maintenance
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Retirement
Disposal
Recycling
Reuse
Refurbishment
Repair
Replacement
Spare Parts
Inventory
Warehouse
Logistics
Supply Chain
Customer
Supplier
Vendor
Partner
Competitor
Market
Industry
Sector
Economy
Global
Local
Regional
National
International
Culture
Society
Community
Family
Individual
Human
Animal
Plant
Ecosystem
Biosphere
Earth
Solar System
Galaxy
Universe
Multiverse
Time
Space
Matter
Energy
Information
Knowledge
Wisdom
Truth
Beauty
Goodness
Meaning
Purpose
Value
Ethics
Morality
Law
Justice
Freedom
Responsibility
Rights
Duty
Virtue
Vice
Happiness
Suffering
Love
Hate
Fear
Hope
Faith
Doubt
Belief
Religion
Spirituality
Philosophy
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Drama
Film
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Painting
Photography
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Waiter
Menu
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Chair
Plate
Fork
Knife
Spoon
Glass
Cup
Napkin
Tablecloth
Candle
Flower
Vase
Centerpiece
Party
Celebration
Holiday
Birthday
Wedding
Anniversary
Graduation
Retirement
Funeral
Memorial
Cemetery
Grave
Tombstone
Epitaph
Obituary
Will
Inheritance
Estate
Trust
Foundation
Charity
Donation
Volunteer
Service
Club
Organization
Association
Union
Cooperative
Corporation
Partnership
Sole Proprietorship
Limited Liability Company
Public Company
Private Company
Nonprofit
Government
Agency
Department
Ministry
Parliament
Congress
Senate
House of Representatives
Assembly
Council
Committee
Subcommittee
Hearing
Testimony
Witness
Expert
Lobbyist
Campaign
Election
Vote
Ballot
Polling Station
Voter
Candidate
Party
Platform
Policy
Legislation
Bill
Act
Statute
Regulation
Rule
Order
Decree
Judgment
Court
Judge
Jury
Trial
Lawsuit
Plaintiff
Defendant
Attorney
Lawyer
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Defense
Evidence
Witness
Testimony
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Sentence
Appeal
Prison
Jail
Parole
Probation
Fine
Penalty
Crime
Criminal
Victim
Police
Detective
Investigation
Arrest
Warrant
Search
Seizure
Interrogation
Confession
Alibi
Motive
Weapon
Gun
Knife
Bomb
Explosive
Terrorism
War
Peace
Treaty
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Enemy
Ally
Soldier
Army
Navy
Air Force
Marine
Coast Guard
Military
Base
Fort
Barracks
Weapon
Ammunition
Tank
Aircraft
Ship
Submarine
Missile
Rocket
Drone
Satellite
Intelligence
Espionage
Spy
Secret
Classified
Top Secret
Confidential
Declassified
Archive
Library
Museum
Exhibition
Collection
Artifact
Specimen
Fossil
Dinosaur
Prehistoric
Ancient
Medieval
Modern
Contemporary
Future
Past
Present
History
Historian
Archaeology
Archaeologist
Excavation
Site
Ruin
Monument
Statue
Memorial
Tradition
Custom
Ritual
Ceremony
Festival
Holiday
Celebration
Parade
Carnival
Fair
Market
Shop
Store
Mall
Department Store
Supermarket
Convenience Store
Gas Station
Car Wash
Repair Shop
Garage
Parking Lot
Parking Garage
Street
Road
Highway
Freeway
Expressway
Boulevard
Avenue
Lane
Alley
Bridge
Tunnel
Overpass
Underpass
Intersection
Roundabout
Traffic Light
Stop Sign
Yield Sign
Speed Limit
Crosswalk
Sidewalk
Curb
Gutter
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Mailbox
Newspaper
Magazine
Book
Publication
Author
Publisher
Editor
Reporter
Journalist
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Social Media
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Homicide
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Thunderstorm
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Eclipse
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Impact
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Extinction
Evolution
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Selection
Species
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Order
Class
Phylum
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Nomenclature
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Type Specimen
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Synonym
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Hybrid
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Cell Line
Culture
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Agar
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Microscope
Slide
Stain
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Fluorescence
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Luminescence
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Chemiluminescence
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Respiration
Metabolism
Enzyme
Catalyst
Reaction
Equation
Stoichiometry
Molecule
Compound
Mixture
Solution
Solvent
Solute
Concentration
Molarity
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Acid
Base
Salt
Buffer
Titration
Indicator
Precipitate
Filtration
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Sublimation
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Activation Energy
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Enthalpy
Entropy
Gibbs Free Energy
Heat
Work
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Second Law
Third Law
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Ensemble
Microstate
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Quantum Statistics
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Real Gas
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Compressibility
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Phase Rule
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Clapeyron
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Triple Point
Supercritical
Surface Tension
Capillarity
Wetting
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Desorption
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Diffusion
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Bioluminescence
Chemiluminescence
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Passivation
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Chronopotentiometry
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Rotating Ring-Disk Electrode
Quartz Crystal Microbalance
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Rutherford Backscattering
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Irrigation
Drainage
Flood Control
Water Treatment
Wastewater
Sewage
Septic System
Landfill
Recycling
Composting
Hazardous Waste
Radioactive Waste
Nuclear Waste
Environmental Impact
Sustainability
Renewable Energy
Solar Energy
Wind Energy
Hydroelectric
Geothermal
Biomass
Biofuel
Fossil Fuel
Coal
Oil
Natural Gas
Petroleum
Refinery
Pipeline
Tanker
Offshore
Drilling
Rig
Platform
Subsea
Riser
Blowout Preventer
Mud
Cement
Casing
Tubing
Packer
Perforation
Fracturing
Acidizing
Production
Enhanced Oil Recovery
Steam Injection
Carbon Dioxide Injection
Water Flooding
Gas Lift
Artificial Lift
Pump Jack
Submersible Pump
Progressing Cavity Pump
Electric Submersible Pump
Gas Compressor
Separator
Dehydrator
Sweetening
Flare
Vent
Emission
Pollution
Air Quality
Water Quality
Soil Contamination
Remediation
Monitoring
Sensor
Data Logger
Telemetry
Wireless
Bluetooth
Wi-Fi
Cellular
Satellite Communication
Radio
Microwave
Fiber Optic
Ethernet
USB
Serial
Parallel
Interface
Protocol
Standard
Specification
Testing
Calibration
Certification
Quality Control
Quality Assurance
Inspection
Audit
Documentation
Report
Presentation
Publication
Patent
Trademark
Copyright
License
Contract
Agreement
Negotiation
Procurement
Purchase
Sale
Invoice
Payment
Budget
Cost
Price
Profit
Loss
Tax
Insurance
Risk
Safety
Security
Emergency
Evacuation
Fire
Explosion
Accident
Injury
Fatality
Training
Education
Research
Development
Innovation
Technology
Engineering
Science
Mathematics
Physics
Chemistry
Biology
Geology
Astronomy
Meteorology
Oceanography
Ecology
Economics
Finance
Accounting
Management
Leadership
Teamwork
Communication
Collaboration
Project
Task
Milestone
Deliverable
Schedule
Resource
Allocation
Planning
Organization
Structure
Hierarchy
Role
Responsibility
Authority
Decision
Problem
Solution
Analysis
Design
Implementation
Operation
Maintenance
Upgrade
Retirement
Disposal
Recycling
Reuse
Refurbishment
Repair
Replacement
Spare Parts
Inventory
Warehouse
Logistics
Supply Chain
Customer
Supplier
Vendor
Partner
Competitor
Market
Industry
Sector
Economy
Global
Local
Regional
National
International
Culture
Society
Community
Family
Individual
Human
Animal
Plant
Ecosystem
Biosphere
Earth
Solar System
Galaxy
Universe
Multiverse
Time
Space
Matter
Energy
Information
Knowledge
Wisdom
Truth
Beauty
Goodness
Meaning
Purpose
Value
Ethics
Morality
Law
Justice
Freedom
Responsibility
Rights
Duty
Virtue
Vice
Happiness
Suffering
Love
Hate
Fear
Hope
Faith
Doubt
Belief
Religion
Spirituality
Philosophy
Art
Music
Literature
Poetry
Drama
Film
Dance
Sculpture
Painting
Photography
Architecture
Design
Fashion
Food
Cooking
Recipe
Ingredient
Kitchen
Restaurant
Chef
Waiter
Menu
Dining
Table
Chair
Plate
Fork
Knife
Spoon
Glass
Cup
Napkin
Tablecloth
Candle
Flower
Vase
Centerpiece
Party
Celebration
Holiday
Birthday
Wedding
Anniversary
Graduation
Retirement
Funeral
Memorial
Cemetery
Grave
Tombstone
Epitaph
Obituary
Will
Inheritance
Estate
Trust
Foundation
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Club
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Government
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Crime
Criminal
Victim
Police
Detective
Investigation
Arrest
Warrant
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Gun
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War
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Enemy
Ally
Soldier
Army
Navy
Air Force
Marine
Coast Guard
Military
Base
Fort
Barracks
Weapon
Ammunition
Tank
Aircraft
Ship
Submarine
Missile
Rocket
Drone
Satellite
Intelligence
Espionage
Spy
Secret
Classified
Top Secret
Confidential
Declassified
Archive
Library
Museum
Exhibition
Collection
Artifact
Specimen
Fossil
Dinosaur
Prehistoric
Ancient
Medieval
Modern
Contemporary
Future
Past
Present
History
Historian
Archaeology
Archaeologist
Excavation
Site
Ruin
Monument
Statue
Memorial
Tradition
Custom
Ritual
Ceremony
Festival
Holiday
Celebration
Parade
Carnival
Fair
Market
Shop
Store
Mall
Department Store
Supermarket
Convenience Store
Gas Station
Car Wash
Repair Shop
Garage
Parking Lot
Parking Garage
Street
Road
Highway
Freeway
Expressway
Boulevard
Avenue
Lane
Alley
Bridge
Tunnel
Overpass
Underpass
Intersection
Roundabout
Traffic Light
Stop Sign
Yield Sign
Speed Limit
Crosswalk
Sidewalk
Curb
Gutter
Drainage
Sewer
Manhole
Fire Hydrant
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Newspaper
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Reporter
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Purification
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Nuclear Magnetic Resonance
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Ultraviolet
Visible
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Reduction
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Electrochemical Cell
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Nernst Equation
Tafel Equation
Butler-Volmer
Marcus Theory
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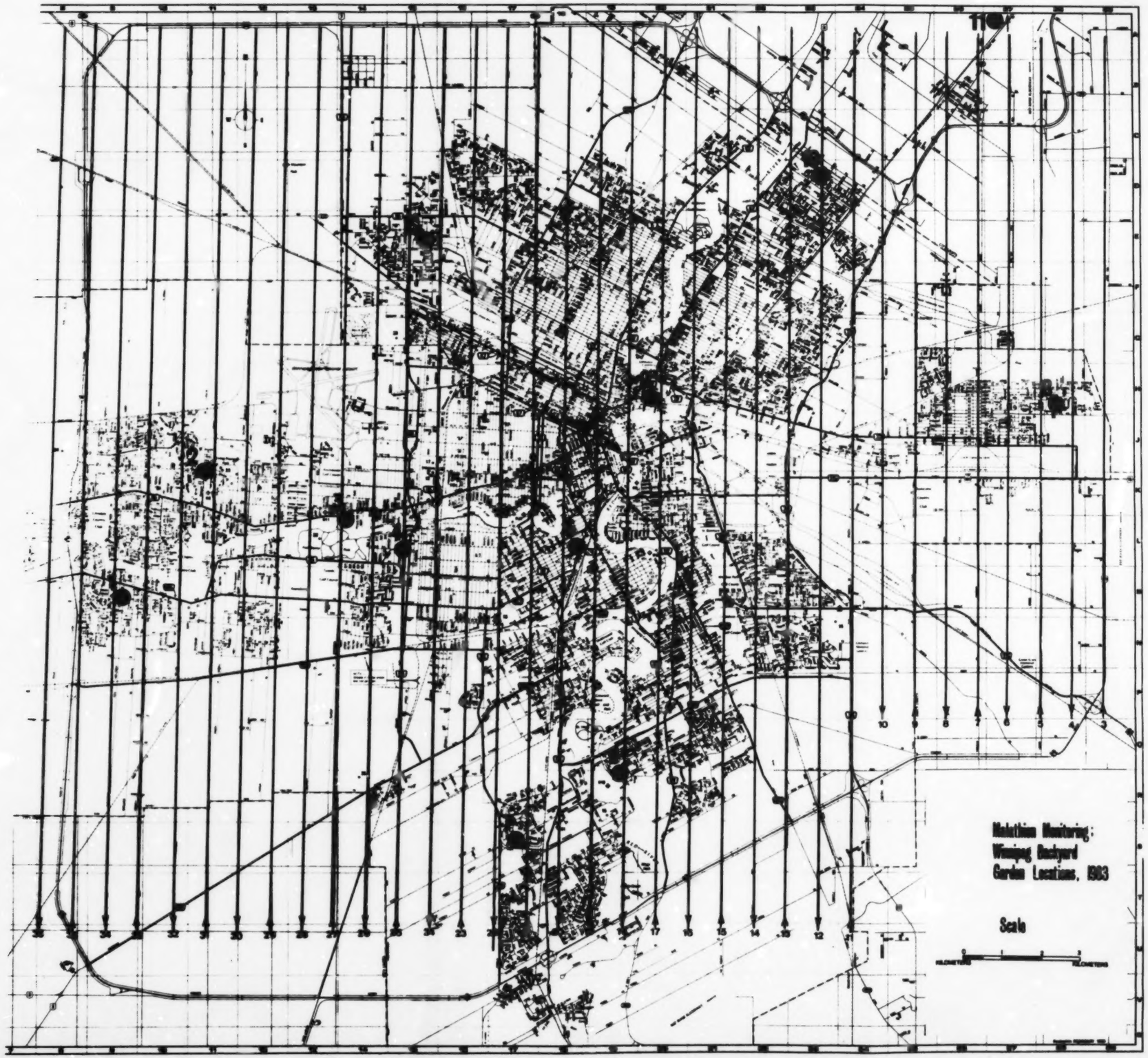
Chronoamperometry
Chronopotentiometry
Rotating Disk Electrode
Rotating Ring-Disk Electrode
Quartz Crystal Microbalance
Scanning Electrochemical Microscopy
Atomic Force Microscopy
Scanning Tunneling Microscopy
Electron Microscopy
Transmission Electron Microscopy
Scanning Electron Microscopy
Focused Ion Beam
Energy Dispersive X-ray
Wavelength Dispersive X-ray
Auger Electron Spectroscopy
X-ray Photoelectron Spectroscopy
Ultraviolet Photoelectron Spectroscopy
Secondary Ion Mass Spectrometry
Rutherford Backscattering
Particle Induced X-ray Emission
Neutron Activation Analysis
Gamma Spectroscopy
Alpha Spectroscopy
Beta Spectroscopy
Liquid Scintillation
Geiger-Müller
Proportional Counter
Ionization Chamber
Semiconductor Detector
Germanium Detector
Silicon Detector
Cadmium Telluride
Gallium Arsenide
Indium Phosphide
Silicon Carbide
Gallium Nitride
Diamond
Graphene
Carbon Nanotube
Fullerene
Buckminsterfullerene
Nanoparticle
Quantum Dot
Nanowire
Nanotube
Nanocomposite
Polymer
Plastic
Rubber
Fiber
Textile
Fabric
Clothing
Shoes
Hat
Glove
Scarf
Tie
Belt
Buckle
Button
Zipper
Pocket
Sleeve
Collar
Cuff
Hem
Seam
Stitch
Thread
Needle
Sewing Machine
Pattern
Cut
Fit
Size
Measurement
Tailor
Seamstress
Designer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